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SUPPLY ASSURANCE IN THE NUCLEAR FUEL CYCLE

by

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ABSTRACT

The economic, technical and political issues which bear on the security of nuclear fuel supply internationally are addressed. The structure of international markets for nuclear fuel is delineated; this includes an analysis of the political constraints on fuel availability, especially the connection to supplier nonproliferation policies. The historical development of nuclear fuel assurance problems is explored and an assessment is made of future trends in supply and demand and in the political context in which fuel trade will take place in the future. Finally, key events and policies which will affect future assurance are identified.

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I. INTRODUCTION

The security of nuclear fuel supply is a source of economic and political concern to many countries. These worries result, in part, from a heightened awareness of the role of energy in national economic health and security in the wake of the 1973-74 oil crisis, and from an increased sensitivity to the vulnerability of foreign sources of energy supply. However, other issues and events specific to nuclear fuel have exacerbated this general assurance problem. The oil crisis increased the importance of nuclear power to Western Europe and Japan, and the resulting large capital-intensive reactor commitments have created their own fuel supply imperatives. The nuclear fuel supply system is also complex, requiring a sequence of processing steps, several of which are highly concentrated in a few supplier countries. Historically, nuclear fuel supply has experienced serious market and political problems, including substantial variations in market conditions, market failures and changes in policies of key suppliers. All of these have contributed to intense concern about the security of fuel supplies in the future.

Nuclear fuel assurance concerns also interact strongly with nuclear technology development plans and with international security considerations associated with nuclear weapons proliferation. The perceived insecurity of supplies of the low-enriched uranium fuel used in today's light-water reactors creates an incentive for some countries to build their own fuel cycle facilities, and to move more rapidly toward new technologies which use less uranium and thereby reduce dependence on others. This desire creates a pressure to commit to commercial development of new technologies earlier than would otherwise be necessary -- perhaps with results less satisfactory from an economic or technical perspective. But the most serious implication of this drive for independence is its effect on the achievment of nonproliferation goals.

Accelerated commitments to enrichment facilities, to spent fuel reprocessing and plutonium recycle, or to plutonium breeders -- all of which could make weapons-usable material more immediately available to more countries -- are now viewed, in the United States and elsewhere, as straining the capabilities of the existing nonproliferation regime. Assurance of low-enriched uranium fuel supply is thus regarded as playing a key role in retarding such proliferation-sensitive commitments. However, this relationship is complicated by supplier imposition of new nonproliferation conditions on access to nuclear fuel that, from a consumer perspective, may lead to a perception of reduced rather than improved assurance.

As a result of these complex interrelated concerns, the issue of nuclear fuel assurance has assumed a central role in U.S. nuclear policies and in international discussions and negotiations. In this paper we explore the web of technical, economic and political factors which underlie the reality, and the perception, of nuclear fuel assurance.

WHAT IS FUEL ASSURANCE?

The term "fuel assurance" refers to a host of issues in nuclear fuel supply. It may refer to the fuel security of a nation, or the fuel acquisition problems of a particular utility; it may relate to the supply of fuel for one's own reactors, or to the guarantee of fuel as a sweetener for foreign reactor sales. Our discussion centers on the nation as the unit of analysis, and though the issue of fuel guarantees may arise in the discussion of reactor competition, our primary concern is with security of supply for a consumer nation's reactors.

With the focus narrowed in this way, the various aspects of the assurance issue can be sorted out on the basis of time horizon. We divide the future (somewhat arbitrarily) into a short-, a medium-, and a long-term perspective.

THE SHORT TERM: RESILIENCE TO CRISIS In the short run assurance concerns result from the possibility of interruption of previously-arranged fuel supplies. A cut-off or delay might result from a plant accident or other force majeure, but the main fear is of political change, either within the supplier country or between supplier and purchaser. The recent Canadian withholding of U_3O_8 shipments covered by shipments covered by contracts with Japan and others is an example.

The effects of such events depend on several factors. First, it matters where in the supply chain the problem occurs. Lead times in the nuclear fuel cycle are long compared to fossil fuels and interruption early in the process (e.g., U_3O_8 supply) is less serious than a problem with enrichment or, even worse, fuel fabrication. Also, the effects of an interruption depend on the size of available stocks, and on the country's ability to gain access to substitute material in the short run, through spot purchases or swap arrangements. Finally, the consequences depend on the role of nuclear power in the economy, and on the magnitude of the interruption relative to the total nuclear fuel requirement.

For a rough measure of short-term assurance, one may estimate the time a national nuclear-electric system can operate in the face of an interruption, assuming no access to supplemental supplies. The numbers are surprisingly large: for a cut-off of uranium supply they range between three and six years for most major nuclear nations, somewhat less for countries with small nuclear programs. For interruption of enrichment supply, the delay before signigicant effect on power output can still amount to several years. This "flywheel effect" is due to the long procurement lead times and the large stocks of fuel now held by many national authorities, processing firms, and utilities.

THE MEDIUM TERM: CONTRACT CONDITIONS In the medium term, over the next decade or so, assurance has to do with the ability of a country to contract for future supplies. Utilities, be they private or government-owned, must commit large amounts of capital to nuclear reactor construction, and insecurity of fuel supply threatens both this investment and the reliability of electricity supply. As a result, fuel insecurity can be a hindrance to nuclear programs in the competition with other forms of electric generation, and a threat to general economic health.

There is no simple index of medium-term assurance, but it can be set out in concept: it is the likelihood that a purchaser can contract for fuel cycle services, under a set of acceptable conditions, and with reasonable certainty that the contract will be fulfilled as written. Further, it is the prospect that a buyer can diversify any residual risks by spreading purchases over multiple suppliers.

The concept of medium-term assurance takes account not only of the terms and conditions of available uranium and enrichment contracts but also involves the likelihood that known resources will actually be exploited. Some nations (notably Australia) loom so large in the uranium picture that the threat of withdrawal from the market (as Australia did from 1972 to 1976) can create problems of medium-term fuel security. In addition, there is uncertainty about the ability of the uranium industry to expand in the medium term, even if exporter nations are willing and the resources are there.

THE LONG TERM: RESOURCE ADEQUACY In the long term, toward the end of the century and beyond, the issue is the uranium resource base--its cost of exploitation and its size in relation to nuclear power programs. Uncertainty about likely resources and reserves at various cost levels is great, and views of the future vary widely. Some analysts regard uranium as a rapidly depleting resource and argue that competition will soon bid up the economic and political costs of nuclear fuel. Others see uranium as a resource whose exploitation is still in its infancy, and regard present estimates as conservative lower bounds on quantities ultimately available. They cite the lack of incentives for exploration in the past, and recurrently unhealthy markets, as reasons to doubt the value of extrapolations based on currently available information. Perceptions of long-term assurance will depend on how this debate evolves.

The linkages between the medium and long term are strong. Uncertainty about the evolution of the LWR fuel supply system, or its continued disruption, will influence the mix of technologies used over the next few decades, as well as the size of the nuclear-electric sector as a whole. If expectations of fuel availability for present converter reactors (or their somewhat more efficient successors) are low, then nations will accelerate research and development, and the deployment of technologies which are much more uranium-efficient. While in principle there are many such technologies, those closest to technological maturity, like the breeder reactor stressed in most programs, involve the use of plutonium fuels. Research and development aimed at early deployment of plutonium breeders involves even earlier commitments to pilot plutonium facilities. For this reason, worries about long-term nuclear fuel availability have a considerable impact on contemporary international concerns.

ORIGINS OF THE PROBLEM, AND TRENDS

In the discussion to follow, we look for the underlying causes of the fuel assurance problem, and the particular events that have made it so acute in the nuclear area. We begin with a brief description of the structure of the industry including its technical aspects, the degree of economic concentration and the overlay of international political institutions that are peculiar to the nuclear industry. Throughout the paper our primary focus is on medium-term assurance, but the consideration of technical structure gives an opportunity to evaluate the current system from the standpoint of crisis resistance or short-term fuel assurance. Because of the long time lags in the fuel cycle, the existence of excess capacity, and the size of current stockpiles, the system now seems quite secure from a short-term perspective.

The discussion proceeds to a survey of the historical roots of the assurance problem. Subsequent to the creation of the nuclear option in World War II, a great many events and factors have contributed to the evolution of the nuclear fuel supply system, and to its problems. The most severe problems occurred in the early to middle years of this decade, with a number of events conspiring to create a crisis of confidence about the security of nuclear fuel supply. Most of these problems are now behind us -- though their legacy of uncertainty is not -- with the important exception of a lack of agreement about the nonproliferation rules under which nuclear trade will take place.

We then turn to a review of current trends in enrichment and uranium markets. Enrichment is and will continue to be in excess supply, due in part to reductions in nuclear power growth expectations but also because of the entry of new suppliers, including the USSR and new European enrichment ventures. As a result, enrichment markets are now entering a period of major change which will provide opportunities for consumers to increase the security of their supply arrangements. Uranium supply is somewhat more uncertain, though the near-term issue here is not one of production capacity but rather of supplier conditions on access. Later, by the end of the 1980s, there is greater uncertainty about uranium production capacity, but this appears to have more to do with uncertainties about nuclear power demand than with resources or technical capabilities. In the concluding section we examine possible problems that may affect fuel assurance in the future and the policy issues which they raise. The most important issue is whether the political uncertainties arising from nonproliferation concerns will continue or be resolved.

II. STRUCTURE OF THE FUEL SUPPLY SYSTEM

To some degree, issues of fuel security are inherent in the structure of the nuclear industry. Fuel cycle technology is complex and expensive, and many countries lack the capability to develop indigenous facilities in the short or medium term. Moreover, supplies of critical materials and services are concentrated in a few countries, leading to fears that existing sources may be used as a political or economic weapon, or may simply turn out to be undependable. Finally, nuclear fuel is inevitably coupled to the problem of nuclear weapons, and to the fabric of treaties, controls, and safeguards that have been designed to curb the proliferation of weapons capability.

Paradoxically, under current circumstances these system characteristics combine to provide a high degree of short-term fuel security. To a large extent, this is due to the technical structure of the industry, and it is to this aspect of the nuclear cycle that we turn first. Then, we review the market structure, and the fabric of political constraints, which are important aspects of the assurance problem in the medium term.

TECHNICAL STRUCTURE

Fuel for a light-water reactor (LWR),the dominant reactor type worldwide, is the result of a long series of processing steps that begins with the mining of uranium-bearing ores and ends with a batch of fuel assemblies which are used to replace, approximately annually, 1/5 to 1/3 of the total fuel material in a reactor. In processing, the uranium ore is milled to recover the 0.1 percent to 10 percent or more uranium contained in it. The result is yellowcake: U_3O_8 with some impurities. The yellowcake is then purified, and the uranium converted to a new chemical compound, UF_6. At this stage uranium contains only about 0.7% of the fissile isotope U235 (the remainder being U238). Of these, only U235 can be fissioned by the low-energy neutrons which mediate the chain reaction.

Since the concentration of U235 in natural uranium is too low to sustain a chain reaction in an LWR, the proportion of this isotope must be increased to about 3% by isotopic enrichment, a technology which has been developed commercially by only a few countries. A fraction of the original U235--variable, within limits, by the enricher--remains as "tails" from the enrichment process. After it leaves the enrichment plant, the enriched UF_6 goes to a fuel fabricator where it is converted to uranium dioxide (UO_2), formed into pellets and fabricated into fuel assemblies. Fuel fabricated for one reactor generally cannot be used in another.

This sequence of processing steps is more complicated than for other energy forms, and it requires more time. An idealized procurement schedule for a pressurized water reactor, one of the two main types of LWR, is shown in Figure 1. There is a rectangle for each step in the process, and the first core (or full) loading and several reloads are shown. The height of each rectangle gives a rough indication of the quantity of material or fuel-cycle services involved in that step, and the length represents the time required. Note that the manufacture of the first core requires more inputs than reloads. Roughly three years are required to produce the initial fueling, and reloads take more than twenty months. When there are uncertainties--as when international purchases are involved or renegotiation of contracts may be required--utilities generally allow still more time between fuel cycle steps.

Thus interruption at early stages of the fuel cycle would not have an immediate effect on output. For example, failure of delivery from a natural uranium supplier would not result in an interruption of electric generation for nearly two years. This is very different from the situation with oil where near-term crises develop rapidly: the time between supplier failure and impact on economic activity would rarely exceed three months for oil. For the nuclear fuel cycle, such a short lag time could occur only in the case of interruption following fuel fabrication.

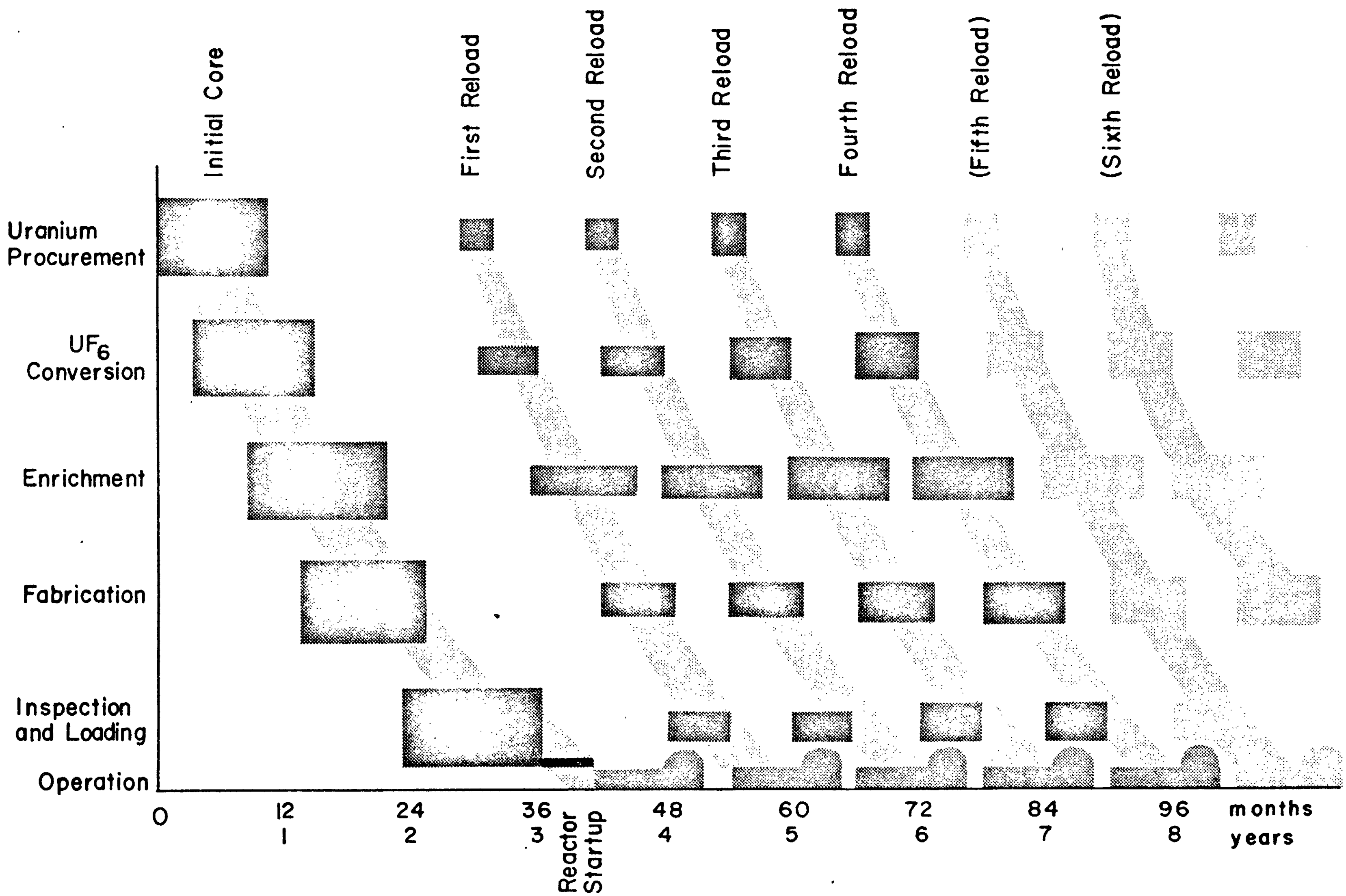

Figure 1. Nuclear fuel cycle lead times for a pressurized water reactor. The shaded blocks show the flow of fuel material through the fuel cycle. The length of each block designates the time needed for each process step while the height of the block indicates the quantity of material or services involved. The first fuel loading requires more than three years to produce and considerably more materials and services than do reloads.

Technical measures may further extend the operation of nuclear plants. Time can be gained by reducing coolant temperature and thus lowering the power output of the plant. Reduction to 75% of full power can add about 4 months operation if initiated early in a burn cycle; reduction to 50% might add 12 months under similar conditions. The extension results both from a reduction in the rate of consumption of fissile material and an increase in reactivity (due to lower temperature) which increases the total fuel burnup possible over the cycle. Late in the burn cycle, only one to three months extension is possible.

The natural flywheel effect of the nuclear supply system is enhanced by the conservative planning of consumers and suppliers. Utilities usually order fuel on the assumption that the reactor will operate at a 75-80% capacity factor. In practice, reactors have been operating at average capacity factors ranging from 42% (Japan, 1977) to 67% (West Germany, 1976). If a supply interruption were to occur, a reactor running at such a lower capacity factor usually could continue operation for a number of months (perhaps 2 to 10) beyond its usual scheduled refueling date.

The mismatch between plans and performance in the past has also resulted in stockpiles of fuel materials. Where it is possible to extend operation of a reactor beyond its refueling date, the stock is held as fresh fuel material; when it proves desirable to refuel on schedule (e.g., between seasonal demand peaks) the stock may be held in reactor cooling ponds as irradiated fuel which has not reached design burnup. In principle, it is possible to reinsert this fuel in the reactor, though safety regulations inhibit such use.

The fact that fuel supply planning is more conservative than actual operations (a practice that is justified by the large magnitude of reactor capital relative to fuel cycle costs) means that other forms of flexibility are available as well. The reduced urgency of some consumers' needs may allow rescheduling (or even reassignment) of material by a fabricator, enricher or other supplier in order to meet the needs of consumers whose fuel has been delayed or damaged. Suppliers also are conservative in their production planning. For example, the U.S. has required enrichment customers to enter into contracts well in advance of reactor startup. Similar commitments have been required of participants in fuel cycle ventures in Europe. Since actual deployment of reactors has not kept pace with the plans on which fuel commitments were made, surpluses of fuel have been accumulating. Many utilities now hold one, two or more years forward supply of nuclear fuel.

Thus, the overall trend in countries with large nuclear programs has been toward large domestic stockpiles of fuel. For example, Italy is entitled to a 25% share of the output of the new Eurodif enrichment venture (discussed below). This share would be enough to provide initial cores for 5000 megawatts-electric (MWe) annually or to sustain 23,000 MWe of nuclear capacity; during the early to mid 1980s total Italian nuclear capacity will be at most 4000 MWe. The surplus material could be stockpiled, or sold, thus contributing to security of supply for Italy or opening alternate sources of supply or stockpiles for other countries.

Such near-term technical flexibility in the nuclear power industry protects countries from serious consequences in the case of brief, occasional interruptions in the supply of fuel. However, it will do little to increase actual assurance if the fuel supply is chronically unstable, or is perceived as being so. The likelihood of interruption and the ability of consumers to deal with fuel supply problems depend crucially on conditions within the markets where these goods are traded. The number of possible points of interruption, the concentration of supply in a few nations, the problems of restarting fuel cycle flows after a disturbance, and the relatively high level of institutional intervention tend to undermine fuel assurance, particularly in the medium term.

MARKET CONDITIONS

Each of the supply stages in Figure 1 is part of a set of interlinked markets in nuclear materials and associated processing services. Figure 2

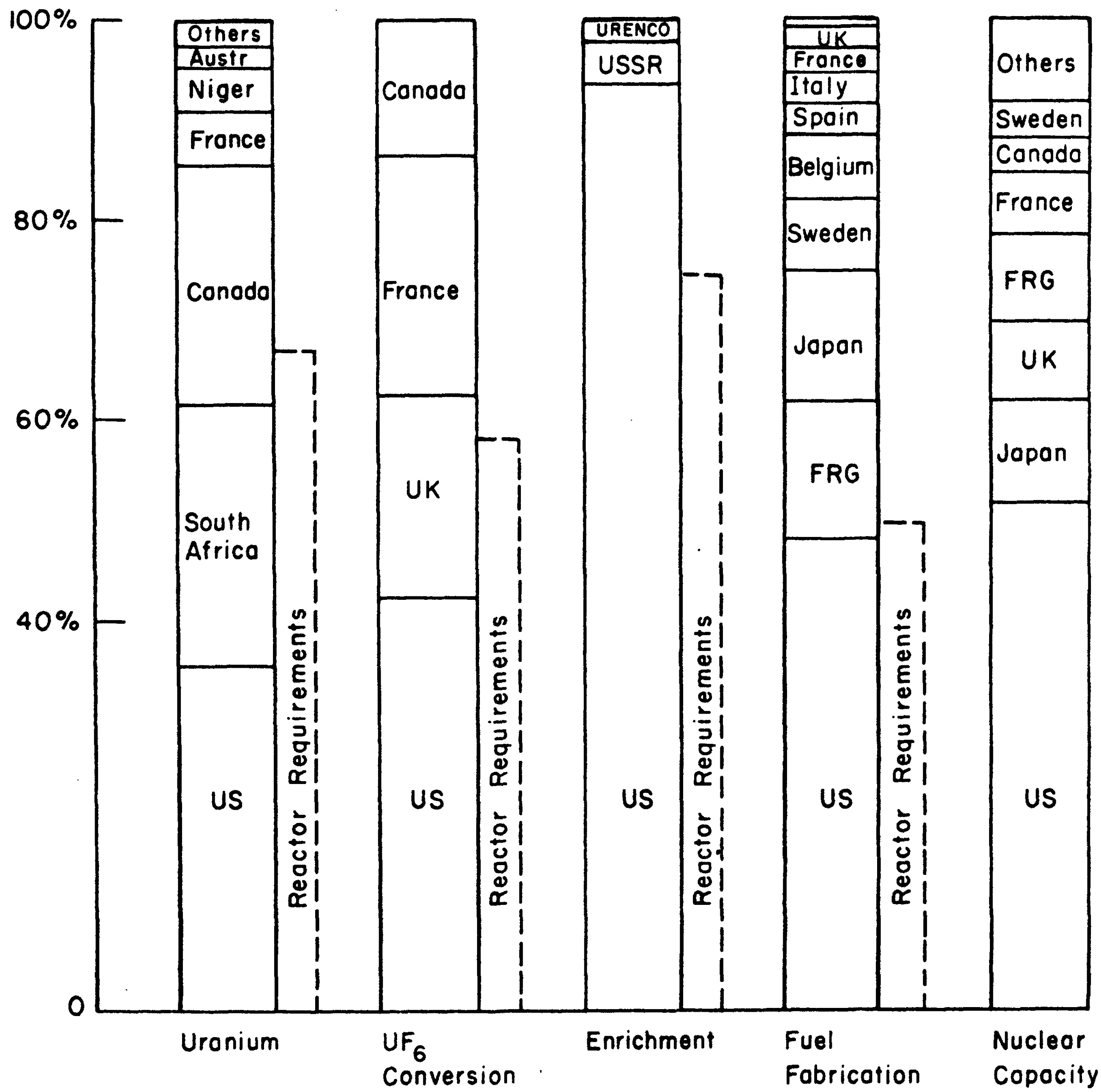

Figure 2. Nuclear fuel cycle capacity distributions and reactor requirements in 1977. The solid histograms show production capabilities for each fuel cycle step, distributed by country; however, not all of the production capacity was utilized in 1977, as indicated by the narrow dashed histograms showing actual reactor requirements in that year. Average reactor capacity factor is assumed to be 70% and enrichment tails assay 0.20%. Source: Japan Science and Technology ed., "Genshiryoku Poketto Bukku (Atomic Energy Pocket Book), 1977 edition". Tokyo: Japan Atomic Industrial Forum, November, 1977. (In Japanese); OECD Nuclear Energy Agency and the International Atomic Energy Agency. 1977. Uranium Resources, Production and Demand. Paris. 136 pp.; and Nuclear Engineering International. November 1976, Volume 21 No. 251.

shows the distribution (as of 1977) among nations of current uranium production capacity, enrichment capacity, UF_6 conversion facilities and fuel fabrication capacity. Also shown is the (1977) distribution of reactors about the world and the demands they put on the fuel system, stage by stage. The various fuel cycle steps are interdependent; for example, enrichment contracts often determine quantities of uranium procured and the timetable for fabrication. In addition, spot transactions, swaps, and sharing arrangements often are worked out by UF_6 conversion firms and fabricators. However, assurance concerns lead to a focus on two parts of the system: uranium supply and enrichment.

ENRICHMENT The international market for enrichment services is highly concentrated, as Figure 2 shows. Currently, the only significant suppliers are the United States and the Soviet Union. The United States has long held a virtual monopoly in commercial enrichment, and contracts with the U.S. Department of Energy currently serve roughly 90 percent of the demand of non-centrally-planned countries.

Sales to European nations by the Soviet Union were the first step in the erosion of the U.S. monopoly position; over the next few years the USSR will provide enrichment services to Western Eurpoe comparable to those from the U.S. European enrichment consortia have also entered, or will soon enter. URENCO, a tri-national consortium of British, Dutch, and West German interests, made its first commercial deliveries in 1976 and has plans to expand its enrichment capacity through the 1980s. EURODIF, a consortium involving France, Belgium, Spain, Italy, and Iran, will make its first commercial deliveries in 1979 and quickly increase its capacity to about half that of the United States.

In addition to these ventures, a number of others were announced in the mid-1970s when it appeared that enrichment capacity might be inadequate in the next decade. The Eurodif partners planned a new venture, Coredif, a 10.8 million SWU plant with ownership shares somewhat different than those of Eurodif. Reduced demand pressure has delayed incentives to build Coredif, though plans have not been formally terminated. South

Africa's Uranium Enrichment Corporation (UCOR) has announced plans to build a commercial facility using a stationary wall centrifuge process. South African sources indicate that a 5 million SWU facility could come on line by the mid- to late 1980s. Brazil's Nuclebras, with the assistance of West Germany, plans a 0.2 million SWU demonstration facility in the mid-1980s using German Becker nozzle technology. Japan's Power Reactor and Nuclear Fuel Development Corporation (PNC) is considering expansion from a current pilot centrifuge plant up to a one million SWU or larger facility by the mid- to late 1980s. At various times, interest in acquiring enrichment capability has been expressed by Australia, India, Iran, Portugal, Sweden and Zaire. Of all these plans, only the Japanese and South Africa ventures are at all likely to make a significant contribution to enrichment supply in the next decade.

Although commercial enrichers do make short-term spot sales of enrichment services under emergency circumstances, virtually all current and future enrichment sales are under long-term contracts. In the past, DOE long-term contracts were of two basic types. In the early years of the U.S. industry, Requirements Contracts were written. Under these contracts enrichment services are supplied to meet the actual requirements of a particular reactor. The contract holder firms up the enrichment delivery schedule six months ahead of the time when the product is needed. The Requirements contract was replaced in 1973 by Long-Term Fixed Commitment (LTFC)contracts. Under this contract customers are required to firm-up the enrichment delivery schedule on a rolling ten-year basis. The U.S. has recently introduced a third contract form, the Adjustable Fixed Commitment (AFC) contract which involves a shorter firm-up period and greater flexibility; those holding LTFC contracts will be able to convert to the new contract form. Adjustments to reflect actual reactor operations cannot be made without incurring penalty charges. Most current and potential foreign enrichers offer some variant of these contract forms. Urenco offers a Requirements-type contract, while Eurodif negotiates contracts more like the AFC contract form. Both set price on a cost-recovery basis, with prices significantly in excess of those charged by DOE. The Soviet Union's Techsnabexport offers contracts for fixed quantities of enrichment services for delivery at specified times; prices are reported to be slightly below those of the U.S.

The international enrichment market is currently undergoing major changes. The first change is structural: the entry of new suppliers will replace monopoly with oligopoly and create opportunities for consumers to diversify risks by contracting with several sources. Moreover, the existence of excess capacity (discussed below) will create even more fluid market conditions, with consumers potentially able to alter their traditional supply patterns more rapidly than if new capacity additions were just adequate to serve new demand. Finally, enrichment contract terms are becoming much more flexible in terms of lead-times, commitment periods, delivery schedules and specification of enrichment tails assay. The latter will increase the elasticity of uranium demand, allowing enrichment services and uranium to be substituted for each other at consumer initiative, within a small range.

URANIUM The production of uranium is concentrated in a handful of countries. As shown in Figure 2, the U.S., South Africa, Canada, France and Niger accounted for 97% of non-Communist output in 1977. Resources are similarly concentrated. Australia, Canada, Niger, South Africa and the U.S. together have 88% of "resources" as estimated by the OECD (1). Expanding the OECD definition to include higher-cost or less-certain deposits would not appreciably alter the overall level of concentration, though the shares of some countries would differ significantly.

The U.S. and France are net importers of uranium, and will continue so in the future. However, since they both import <u>and</u> export (with a net import balance) they represent opportunities for diversification of supply, and can thus improve short-term assurance against the failure of supply from any one country. On the other hand, if the concern is power over market <u>price</u>, it is more informative to look at the level of concentration among net exporters. Here the concentration is no less great: if one sets aside the U.S. and France, then South Africa, Canada and Niger account for 95% of remaining production.

We also can make a crude estimate of the concentration of reserves available for export in the medium-term future. For this purpose, one should subtract from the OECD total the entire U.S. and French reserves, and 21% of Canadian reserves (the allotment required under Canada's domestic allocation program). South Africa, Australia, Niger and Canada then turn out to have 84% of the remaining reserves, and therefore groups of these countries have the possibility of cartel-like control of the world price of U_3O_8.

A variety of firms and agencies participate in uranium production. First, producer country governments are directly involved in resource exploitation. In Canada, for example, Eldorado Nuclear Ltd., a Canadian crown corporation, owns the Beaverlodge mine in Northern Saskatchewan. Canadian provincial governments are part owners of several mining ventures. The South African government owns 25% of the Rossing operation in Namibia through its Industrial Development Corporation (though the continuation of this relationship is an issue in the independence struggle). France, Niger, Gabon, and Australia all have significant governmental interests in their domestic uranium industries.

A second group of participants consists of consumers who began in the mid-1970s to acquire direct interest in uranium production. In a recent Department of Energy survey (2), 30 of 65 responding U.S. utilities reported some direct involvement in uranium production. Countries with major import requirements are moving aggressively to acquire interests in foreign uranium production ventures. This is especially true of Japan, West Germany, and France. The means of foreign involvement is through government corporations or private firms acting with official backing. Examples would be Germany's Urangesellschaft or France's AMOK.[1] In the

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[1]A detailed description of these ventures is provided in a study by NUS Corporation (3).

case of companies like these it is often difficult to separate national interest from commercial motivations.

The third major group consists of private companies which are commercially motivated. Production is dominated by large companies but, especially in the U.S., there is an important fringe of smaller producers. Because of the large scale and high risks, joint ventures are common.

For a rough idea of the relative importance of the three groups, one can calculate the shares of production and reserves attributable to each. In Australia, Canada, Niger and South Africa, 14% of production (and 13% of reserves) are directly controlled by producer country governments. Importer country governments, and private companies which appear to have strong ties to these governments, account for 17% of production (and 9% of reserves). Other private companies account for 66% of production and 77% of reserves. (These figures do not total to 100% because the ownership of a small amount of production and reserves could not be identified.) Special mention should be made of Rio-Tinto Zinc, a U.K. based multi-national conglomerate with important holdings in Canada, Australia, and South Africa. Through various affiliates, this firm controls approximately 25% of total industry production and 24% of reserves worldwide.

These figures only give the roughest impression of control over production and reserves. However, they are sufficient to indicate that consumer country governments do not have a dominant influence in the market through direct involvement of government agencies or their proxies. To the extent that is possible to separate public and private motivations, commercially-motivated companies appear to play a strong role at this stage of the fuel cycle. However, this activity often must take place within the constraints of the export policies of producer governments which have substantial economic or political interests in uranium and are in a position to exercise considerable market power.

Long-term contracting is predominant in this industry, and a typical contract seems to be between 10 and 20 years. The U.S. market is the best documented. According to a recent FTC study (4), long-term contracts currently account for about 75% of sales by U.S. producers, and this percentage has been increasing. For Canada, as of the beginning of 1978 there were export contracts approved (5) totalling some 76,000 STU_3O_8,[2] with delivery scheduled in some cases into the 1990s. By comparison, Canada's production in 1977 was about 6,100 STU_3O_8. Australia has about 11,000 tons in outstanding commitments but its production level is only about 1,000 tons per year at present (3). The contract situation in South Africa is not well known because of secrecy laws.

Current contracts generally specify a base price with provision for escalation. The escalation clauses are tied either to the specific costs of the supplier or to general inflation indices. Many contracts include so called "market price" provisions which provide that if the spot price at time of delivery exceeds the escalated base price then some specified percentage of the difference (sometimes 100%) will be added to the base price. Another common contract provision calls for the purchaser to provide a portion of project financing, sometimes on an interest-free basis.

The spot market is thin, and there is no organized market on the order of the London Metals Exchange or the Commodity Exchange of New York. However, there are brokers who are in the business of arranging uranium transactions.

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[2] Different units are used to quantify uranium output. In the U.S., quantities are usually stated in short tons of U_3O_8 (STU_3O_8). In Europe, quantities may be given in metric tons of uranium metal (MTU). Elsewhere, other units such as metric tons of U_3O_8 (MTU_3O_8) may be used. The conversion factors are: 1 MTU equals 1.3 STU_3O_8 equals 1.18 MTU_3O_8.

INSTITUTIONAL FRAMEWORK

Nuclear trade takes place within a number of unilateral, bilateral, and multilateral constraints. Although international commodity trade is often subject to political controls, the rules governing nuclear fuel are particularly complex. Each cycle step can occur in a different country, under different legal and political conditions. Moreover, governments in industrialized countries have a long history of involvement in the nuclear industry and often are responsible for research and development, finance, and export promotion. The result is a set of political restraints and interventions which have a considerable effect on the supply of nuclear fuel.

Since supplies of uranium and enrichment are concentrated in a few countries, the current enrichers (U.S. and USSR) and the large uranium exporters (Australia, Canada and South Africa) are in a position to impose political conditions on the export of fuel. Below, in a section on the history of the assurance problem, we review the development of the policies of these governments in recent years. To prepare for that discussion, it is useful to look briefly at the international structure within which nations with nuclear power programs or industries operate, with special attention to the International Atomic Energy Agency, the Non-Proliferation Treaty, and Euratom.

IAEA SAFEGUARDS The International Atomic Energy Agency serves a number of functions, including research, education, and nuclear promotion. But for the purposes of this discussion, the most important aspect of the Agency is the nuclear safeguards system which it administers. The IAEA system interfaces with a number of national control systems, and with the internal system of the Euratom nations.

The objective of the safeguards system is to provide "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons...and deterrence of such diversion by the risk of early detection" (6). The safeguards are based on a system of materials accountancy which attempts to strike materials balances for various facilities, accountancy regions, and for international flows. The accountancy system is backed up by on-site inspection of a nation's accounting records, and of the safeguarded facilities themselves. Also, the IAEA is taking an increasing role in advising governments on procedures for physical security of nuclear materials.

The detailed arrangements for participation in the system by a nation, or by a group such as Euratom, are negotiated case by case with the IAEA (7). It is important to note that national safeguards systems vary considerably and that some of a nation's facilities may be under safeguards while others are not. For example, almost all major commercial nuclear power plants fall under the system (some at the insistence of the supplier country), but such involvement in the system does not necessarily imply a commitment to subject all nuclear facilities to international surveillance.

THE NUCLEAR NON-PROLIFERATION TREATY The NPT contains two basic obligations, one attaching to nuclear-weapon states and the other to non-nuclear-weapon states. Each nuclear-weapon state undertakes not to transfer nuclear weapons, or control over those weapons, directly or indirectly, and not to assist, encourage, or induce any non-nuclear-weapon state to manufacture or otherwise acquire nuclear weapons or control over them (Article I). Each non-nuclear-weapon state undertakes not to receive nuclear weapons or control over them, not to manufacture or otherwise acquire nuclear weapons, and not to seek or receive any assistance in their manufacture (Article II).

Under the safeguards provisions of Article III, each non-nuclear-weapons party to the Treaty is obligated to apply IAEA safeguards to <u>all</u> nuclear facilities. Each party to the Treaty also undertakes not to export fissionable material--or equipment for the use, processing or production of fissionable material--unless IAEA safeguards are applied.

In complement to these commitments, all parties to the NPT "undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy." (Article IV) This obligation has generally been interpreted as flowing from the nuclear-weapons states to the non-nuclear weapons states. However, there has been difficulty in agreeing on which materials and technologies are appropriate to the "peaceful uses" criterion. It has generally been the policy of the U.S. -- and more recently of other suppliers -- that proliferation-sensitive technologies, such as reprocessing or enrichment, or materials, such as plutonium, are not included under the NPT obligation.

With the exception of France and Spain, all major industrial countries have signed or ratified the NPT. A number of other countries have not done so--among them are Argentina, Bangladesh, Brazil, Chile, India, Israel, South Korea, Pakistan, and South Africa. As noted earlier, however, even in these countries many civilian nuclear power facilities are under IAEA safeguards. In return for assistance in meeting nuclear energy needs, the customer state accepts the intrusion of safeguards on its sovereignty.

EURATOM Established by the Treaty of Rome in 1957, Euratom was designed to serve the collective interests of European nations[3] in competition with the U.S. Originally, the treaty called for a supply agency with exclusive rights to contract for nuclear materials within and outside the European community. Drafted in the atmosphere of the Suez crisis, the exclusive trade provision was meant to prevent discrimination in access to fuel supplies (enrichment or uranium) which might occur with separate bilateral arrangements or any advantage to particular countries in a supply crisis.

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[3]At the outset, Euratom included Belgium, the Netherlands, Luxembourg, France, Italy and the Federal Republic of Germany. In the late 1960s, the Commissions of Euratom, the European Economic Community, and the European Coal Commission were combined in the European Communities; the U.K., Ireland and Denmark became EC members in 1973.

The exclusive trade function was brought into question in the mid 1960s when France sought nuclear fuel supplies outside the Euratom supply channels. In 1971, France unilaterally arranged the purchase of enrichment services from the Soviet Union, an action ruled against by the European Court of Justice but with little effect. The function of the Supply Agency has remained an issue within the Community; however, it generally appears to act as a supply channel (for example, U.S. enrichment contracts for German reactors are between the U.S. and Euratom) rather than as a purchasing agent, a rather different market role.

From the beginning, the Euratom agreement provided for a free flow of material and information among members. Also, Euratom has had its own internal safeguards system, which is now in the process of being coordinated with the accountancy framework of the IAEA. In recent years, difficulties have arisen because some supplier states have insisted on acceptance of IAEA safeguards or other conditions on individual Euratom nations, resulting in conflicting safeguards requirements and European resistance to this intrusion on regional sovereignty arrangements. In particular the Euratom principle of free flows of material among members clashes with "prior approval" clauses for retransfers in some supplier contracts (discussed below). At this point some Euratom agreements with major suppliers are interim in nature, and the characteristics of ultimate fuel supply arrangements are not clear.

As this snapshot makes evident, the special technical, market and institutional structure of the nuclear fuel cycle has a major effect on fuel supply arrangements and on fuel assurance. Supply is in the hands of a few nations, and the proliferation problem brings an unusual degree of policy intervention by national and international authorities. Industry structure is not the whole story, of course; the nuclear fuel supply system has had a particularly troubled history. We proceed next to a review of the events that have helped make nuclear fuel such an intense focus of international concern.

III. HISTORICAL DEVELOPMENT OF THE FUEL ASSURANCE PROBLEM

The nuclear fuel assurance problem has deep historical roots. In addition to difficulties originating in the evolving industry structure, fuel assurance has been influenced by the construction--and revision--of international political regimes for managing proliferation risks, and by the commercial ambitions of suppliers of uranium, fuel cycle services and reactors. Changes in domestic policies and political conditions in supplier and consumer countries also have had major effects, as has the struggle toward new forms of economic and political relationships between developing and developed countries. Finally, there have been fundamental changes in attitudes towards energy and its relationship to economic and political security.

In reviewing this history, it is convenient to talk in terms of three eras:

- <u>The emergence from military programs</u>. The late 1940s to about 1960: the initial development of reactor technology and fuel cycle facilities under government sponsorship.
- <u>The surge of commercial and political development.</u> The years 1960 to about 1973: the beginnings of commercial development of nuclear power and the emergence of an international nonproliferation regime.
- <u>The period of conflict and instability</u>. Roughly 1974 to the present: uncertainties, conflicts and market failures, in the context of heightened concerns about energy and security.

The boundaries between eras are not precise and the seeds of one era's problems (and of some of their solutions) can usually be found in preceding periods. Nonetheless, this simple breakdown does help in sorting out the events of the past three decades.

EMERGENCE FROM MILITARY PROGRAMS

In the United States, the era of commercial nuclear power began with the Atomic Energy Act of 1946; the first proposals for an international regime governing nuclear power were contained in the Baruch Plan of the same year. The U.S. Act legislated civilian exploitation of nuclear-electric power, but with a federal monopoly on nuclear technologies and fuel. The Baruch Plan, presented to the United Nations in June of 1946, called for a similar arrangement internationally--i.e., an International Atomic Development Authority, managing all phases of the development and use of atomic energy, including nuclear fuel. The Baruch Plan eventually failed, and by the early 1950s independent nuclear research and power programs were going ahead in several non-nuclear-weapon states.

In December 1953, President Eisenhower delivered his "Atoms for Peace" speech before the U.N., calling for international cooperation in the development of nuclear power, including assistance in research and development and the provision, by the U.S. and other countries, of nuclear fuel and other materials. Implementation of the 1953 proposal required domestic U.S. legislation--the Atomic Energy Act of 1954--rescinding some of the secrecy provisions of the 1946 Act and authorizing international cooperation.

This cooperation took the form of bilateral Agreements for Cooperation between the U.S. and foreign governments (22 in 1955 alone). The Agreements, which first emphasized research activities but eventually included power reactors and fuel, generally included safeguards and inspection provisions. The United States also reserved the right to approve plans for reprocessing fuel it had supplied, to approve re-transfers to third countries, and to designate storage facilities for excess fissionable material (such as plutonium) or to purchase such excess material. Since all parties foresaw the eventual use of plutonium in nuclear power programs, these provisions were not seen as restricting its use for reactor fuel.

The creation of the International Atomic Energy Agency (IAEA) in 1957, presented opportunities to put safeguards and fuel supply under an international institutional umbrella. But delays in implementing such a regime--combined with the reluctance of some nations to put their nuclear futures in multilateral hands, and Congressional reservations about a possible loss of influence--resulted in bilateral agreements continuing to dominate technology and fuel transfers for many years. Early expectations that the IAEA would function as an international fuel authority, with safeguards following flows of material, were never fulfilled.

The 1950s also saw the beginning of power reactor development and deployment, first in the USSR (a five MWe plant in 1954) and then in the United Kingdom (four 50 MWe graphite-moderated natural uranium reactors in 1956). In the United States, development of the more complex pressurized water reactor (PWR) for use in submarines led to the Shippingport nuclear power plant in 1957. The boiling water reactor (BWR) was first utilized commercially at Dresden, Illinois in 1959. Both reactor types made use of the low enriched uranium producible in large quantities in the United States enrichment plants, which had been constructed for weapons purposes in the 1940s.

During this period, uranium production was stimulated and sustained by the military procurement programs of the United States and the United Kingdom (and later France). Canadian production began in the early 1940s; a domestic U.S. industry was initiated with AEC encouragement in 1948; and production in Australia and South Africa began in the early 1950s, with purchases by the U.S. and the U.K. In all cases, production was encouraged by a variety of consumer and producer government incentives, including discovery rewards, guaranteed purchase prices and tax concessions. These encouragements were effective, as can be seen in Figure 3.

Throughout this period, the United States played a dominant role, due to its general importance in the post-war world, its leadership in technology, and its monopoly position in nuclear fuel supply. From 1956

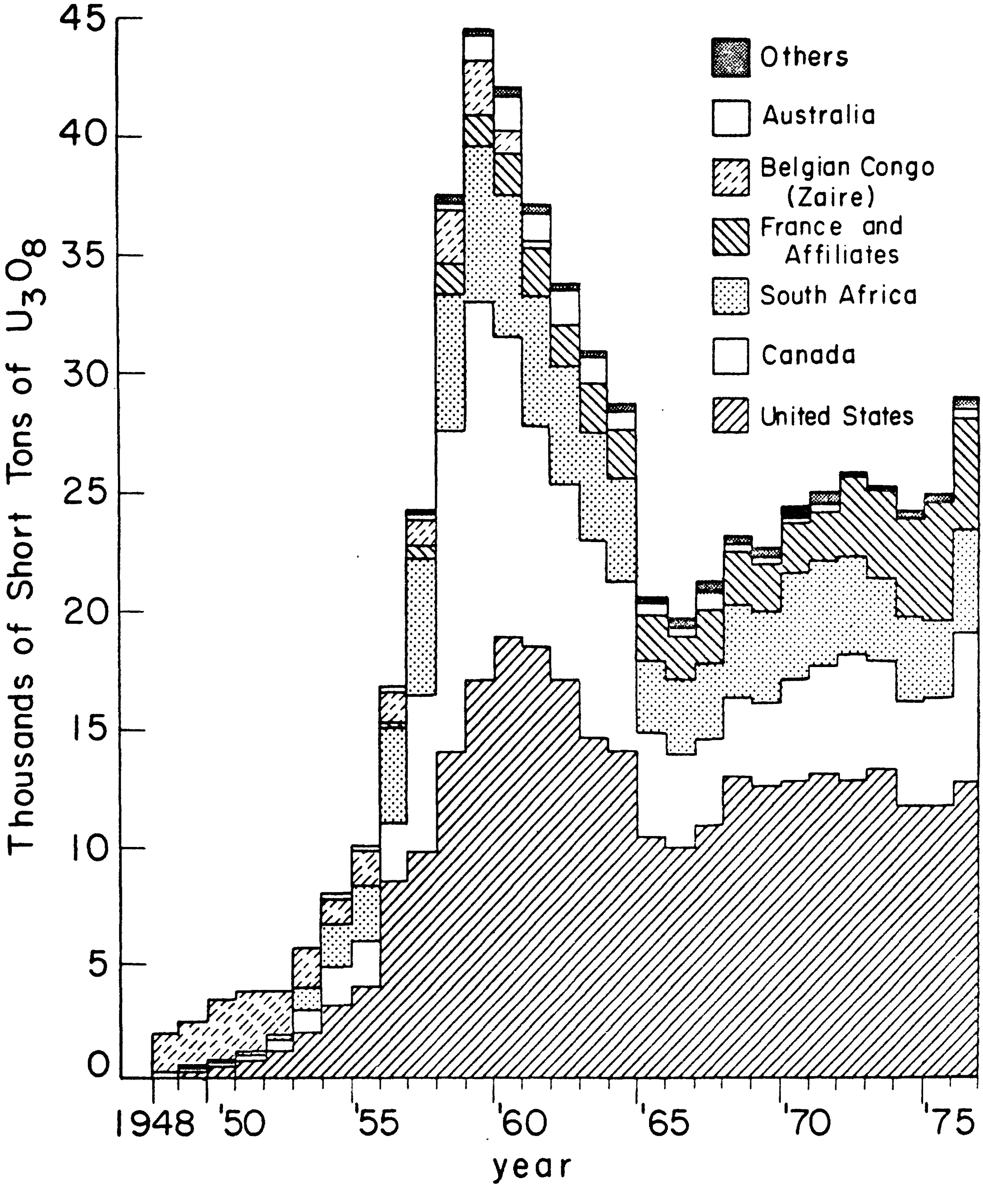

Figure 3. Uranium production 1948-1976. Data up to 1971 are from U.S. Geological Survey Professional Paper 820, 1973; thereafter from Uranium Resources, Production and Demand, a joint report by the OECD and the IAEA, December 1977.

until mid-1961, the U.S. government--which had sole domestic control of U.S. uranium and enrichment--sold (or leased) enriched uranium for research and power uses to other countries, under bilateral Agreements for Cooperation. At this time, the material was owned by the U.S. or the recipient government, not by private parties. In 1959, the U.S. Export-Import Bank began to finance sales of power reactors and fuel through loans and financial guarantees, thus signaling a national commercial interest in nuclear power trade.

THE SURGE OF COMMERCIAL AND POLITICAL DEVELOPMENT

The 1960s and early 1970s saw further development of the institutional and political framework, along with the first commercial investments in nuclear power. However, as discussed below, these developments did not deal entirely adequately with political problems, and conditions in the uranium industry were far from healthy. Thus, while the 1960s were an era of major progress, they also contained the seeds of problems which were to bring a crisis in the mid-1970s.

GROWTH IN INTERNATIONAL REACTOR SALES In the 1960s the first orders were placed for power reactor exports. By 1966, Canada had sold 225 MWe of heavy water reactors to Pakistan and India, and the United Kingdom had sold Magnox reactors to Japan and Spain. Otherwise, the export market was dominated by the United States: Westinghouse sold eight PWRs (2264 MWe) to seven countries, and General Electric sold 11 BWRs (2369 MWe) to eight countries by the end of the decade. During this period, Canada was installing heavy-water reactors and the United Kingdom and France were deploying gas-cooled, graphite-moderated reactors of their own design. In the Federal Republic of Germany, AEG began to sell reactors under license from General Electric. In Japan, three companies began to develop light water reactors for domestic use, under license from U.S. manufacturers.

Major changes came between 1967 and 1969 with the formation of Framatome in France, Kraftwerk Union (KWU) in Germany, and ASEA-Atom in Sweden.

Direct government participation was involved in all but KWU. Framatome began to produce PWRs under Westinghouse license for domestic use. ASEA-Atom developed BWRs of its own design, and KWU began to develop its own PWRs. KWU secured its first PWR orders in 1969 (to the Netherlands), while Framatome did not make export sales until 1974, when it sold four PWRs to Belgium and Iran. As will be seen below, the beginning of competition for international reactor sales put new strains on the nuclear fuel supply system, and on the nonproliferation regime.

INSTITUTIONAL CHANGES In the 1950s, efforts to provide a political context for nuclear development focused on bilateral agreements and regional integration in Western Europe. In the 1960s increased attention was drawn to the need for a stronger global system. Beginning in 1964 (with intensive negotiations with India), the U.S. began to shift bilateral safeguards agreements to trilateral agreements including the IAEA. However, the IAEA functioned as manager of fuel cycle flows only in a few cases where the recipient country wanted the IAEA to act as the supply channel.

The major institutional achievement of this era was the Non-Proliferation Treaty (NPT) which was opened for signature in 1968 and which took effect in 1970. As noted above, the Treaty represents an agreement between weapons and non-weapons states, involving pledges of peaceful nuclear cooperation in exchange for agreement not to develop nuclear weapons and to accept safeguards on <u>all</u> nuclear power activities. The interpretation and implementation of these provisions has been a continuing and controversial process, with significant consequences for trade in nuclear fuel. However, from the standpoint of nuclear power development and the stability of fuel supply arrangements, this was a time of optimism about the possibility of separating nuclear power from nuclear weapons.

DEVELOPMENTS IN THE FUEL CYCLE Until the early 1970s nuclear fuel supply was primarily an issue of enrichment services, and the history of enrichment was mostly one of U.S. policy initiatives. From a consumer perspective, uranium supply was not a problem; the production capacities built up in the 1950s were far larger than commercial demand. Moreover, as the principal source of enrichment, the U.S. often provided the uranium from its own stockpiles, which were increasing due to domestic purchase programs. Outside the U.S., the uranium industry picture was one of severe depression, in the trough between military use and the buildup of civilian nuclear power.

<u>Uranium</u> In 1959, the United States, foreseeing a saturation of weapons needs, announced that it would no longer make foreign purchases of uranium; most existing purchase contracts were to expire by the early 1960s. The result, especially in Canada, was the near collapse of the uranium industry. As shown in Figure 3, Canadian production dropped from more than 12,000 STU_3O_8 in 1959 to about 3,000 tons in 1965. Even this level was sustained only through a government stretch-out program, a transfer of contracts to low-cost producers, and the buildup of a government stockpile. Only 4 out of 28 producers remained active.

In Australia, the impact was not as great, due to the relatively low level of production and the high degree of government participation and stockpile building. In South Africa, the impact of reductions in exports was small since most uranium production was a by-product of gold mining; the uranium actually produced after 1960 (about half the peak rate) was stockpiled. In 1967, the South African government legislated private ownership of uranium and transferred its calcining facility to the Nuclear Fuels Corporation of South Africa, Ltd. (NUFCOR), which now acts as the uranium marketing agent for the gold-mining companies, subject only to the export controls of the South African Atomic Energy Board.

In the United States, government stimulation of the uranium industry ended with a moratorium on new contracts in 1958. From 1962 to 1966 the AEC carried out a maintenance program in which there was an annual 500 STU_3O_8 limit per property and a fixed price of \$8 per pound. The program sustained the industrial base while limiting the further growth of what was already a large stockpile (about 50,000 STU_3O_8, excluding military stocks). However, the reduction in government demand--from a high of 17,600 STU_3O_8 in 1961 to 10,200 STU_3O_8 in 1966--resulted in considerable contraction in the domestic industry and reduced exploration. When expected power-plant demand failed to materialize, the AEC began to stretch out its contracts; by 1970 prices averaged $6 per pound. The price history is shown in Table 1. Prices of uranium had fallen since the mid-1950s, but the fall in real prices was even more severe, as the table shows.

In 1964, the Atomic Energy Act was amended to allow private ownership of nuclear fuels. In 1966, a year which also saw the first big surge in domestic reactor orders (20 reactors with a total capacity of 16,400 MWe) the United States instituted an embargo on the import of foreign uranium for enrichment for use in domestic reactors. This move isolated foreign producers from the first surge of U.S. demand (only three reactors were ordered outside the U.S. in 1966). The first private purchases of uranium in the U.S. began in 1967 and rose rapidly to 12,700 STU_3O_8 in 1971, when the AEC ended its purchase program. As a result, uranium demand in the United States was kept relatively constant during the transition from military to civilian use.

Enrichment The effects of fuel cycle developments on nuclear power came most immediately from changes in U.S. enrichment policy. The 1964 Atomic Energy Act changed the terms of enrichment availability for domestic and foreign customers. The new policy allowed toll enrichment of uranium procured abroad, though the AEC would also sell uranium from U.S. stocks if requested. Whereas previous procedure had been to provide whatever amounts of enriched uranium might be desired by bilateral partners, the new policy was to provide material under the long-term contracts discussed above. The purpose of these contracts, beginning in 1968, was to allow longer-term planning by the builders of an expected wave of new power plants, and by the AEC in its enrichment operations.

The revision in U.S. enrichment contracting represented only a small change in the U.S. role in the international fuel supply system.

Table 1

Uranium Spot Prices in the U.S.

($/lb U_3O_8)

	Current Dollars[a]	Deflated[b]
1950	$9.20	$18.90
1955	12.50	22.00
1960	8.80	13.90
1965	8.00	12.10
1970	6.20	7.00
6/73	6.50	6.10
12/73	7.00	6.30
6/74	10.50	8.40
12/74	15.00	10.80
5/75	21.00	14.60
8/75	26.00	17.80
12/75	35.00	23.80
4/76	42.30	28.30
1/78	42.90	26.70

Notes:

a. Nominal price per lb U_3O_8; 1950-1967 from USAEC purchases, ERDA, Statistical Summary of the Uranium Industry (1976); 1968-1978 from NUEXCO Spot Market Price reports.

b. Deflated by the GNP Implicit Price Index for Non-Residential Structures (1972 = 100).

However, it came at a time when the international commercial context was changing. Other industrialized countries were beginning to enter international reactor markets, and they very likely saw the U.S. monopoly of enrichment as putting them at a commercial disadvantage. The "privatization" of nuclear fuels--part of an overall effort by the AEC and the Nixon Administrations to put all of nuclear power on a commercial footing--implied that fuel supply could become tied to private commercial ambitions in the U.S. as well as to governmental international security interests. The U.S. dominance of reactor orders abroad could only increase such concerns. While this commercial motive may have been relatively unimportant in U.S. decisions, attitudes abroad clearly reflected a growing concern about U.S. commercial dominance and revealed the difficulty of distinguishing between commercial and international security motivations in the new atmosphere of international competition.

One result of these concerns was increased interest in European enrichment projects. In 1968, FORATOM, the European nuclear industry organization, had begun plans for ventures which would provide increased autonomy. In 1970, Germany, the Netherlands and the U.K. established Urenco, an enrichment venture based on centrifuge technology. In 1972, the Eurodif enrichment consortium was chartered, using French diffusion technology. Also in 1970, European utilities and reactor companies began to contract with the USSR's Techsnabexport for considerable quantities of enrichment services to be delivered between 1974 and 1990. West Germany has been the largest purchaser, though others include Sweden, Spain, France, Belgium, Finland, Italy, Austria and the U.K. These contracts with the USSR serve to decrease dependence on the U.S. during the few years remaining before Urenco, Eurodif and other ventures reach full output.

THE PERIOD OF CONFLICT AND INSTABILITY

By the early 1970s, a number of processes were under way which ultimately would alter perceptions of nuclear fuel security, and affect the viability of the nuclear option itself. There were changes in U.S.

policy regarding enrichment, including new efforts to transfer enrichment to the private sector and a change to long-term fixed commitment contracts. In 1974 the U.S. closed its books to further enrichment orders. At the same time, the uranium industry was on its way from a buyer's to a seller's market, with additional disruptions induced by the unexpected loss of Australia as a prospective supplier, massive sales by Westinghouse of uranium for which it did not have contracts with primary producers, and changes in Canada's rules for holding domestic reserve margins. These events and their interrelations are sketched in Figure 4.

Concurrently with these changes, competition for reactor orders was increasing with the entry of European vendors, and the focus of sales efforts was shifting to the developing countries. This competition, combined with the drive for nuclear autarky in Western Europe, served to accelerate technological change and increase the pace of commitments to plutonium fuels, breeder reactors, and indigenous enrichment and reprocessing plants. And, in the midst of all this came the Indian nuclear explosive test. The Indian explosion, coupled with plans for transfers of proliferation-sensitive technologies to other LDCs, raised fundamental questions about the effectiveness of the existing non-proliferation regime, and led to retroactive as well as prospective changes in the political conditions for fuel exports from the U.S. and Canada.

All these events occured in the space of five or six years and were highly interdependent. The net result was a sharp decline in the perceived security of nuclear fuel supply. In the following sub-sections, we look at these events in more detail, focusing on developments in enrichment and uranium markets and in the national policies that determine the conditions of nuclear fuel trade.

ENRICHMENT Because of the dominant role of the U.S. in enrichment, its domestic policies could not help but affect nuclear fuel supply and nuclear development. The policy changes of the early 1970s had a

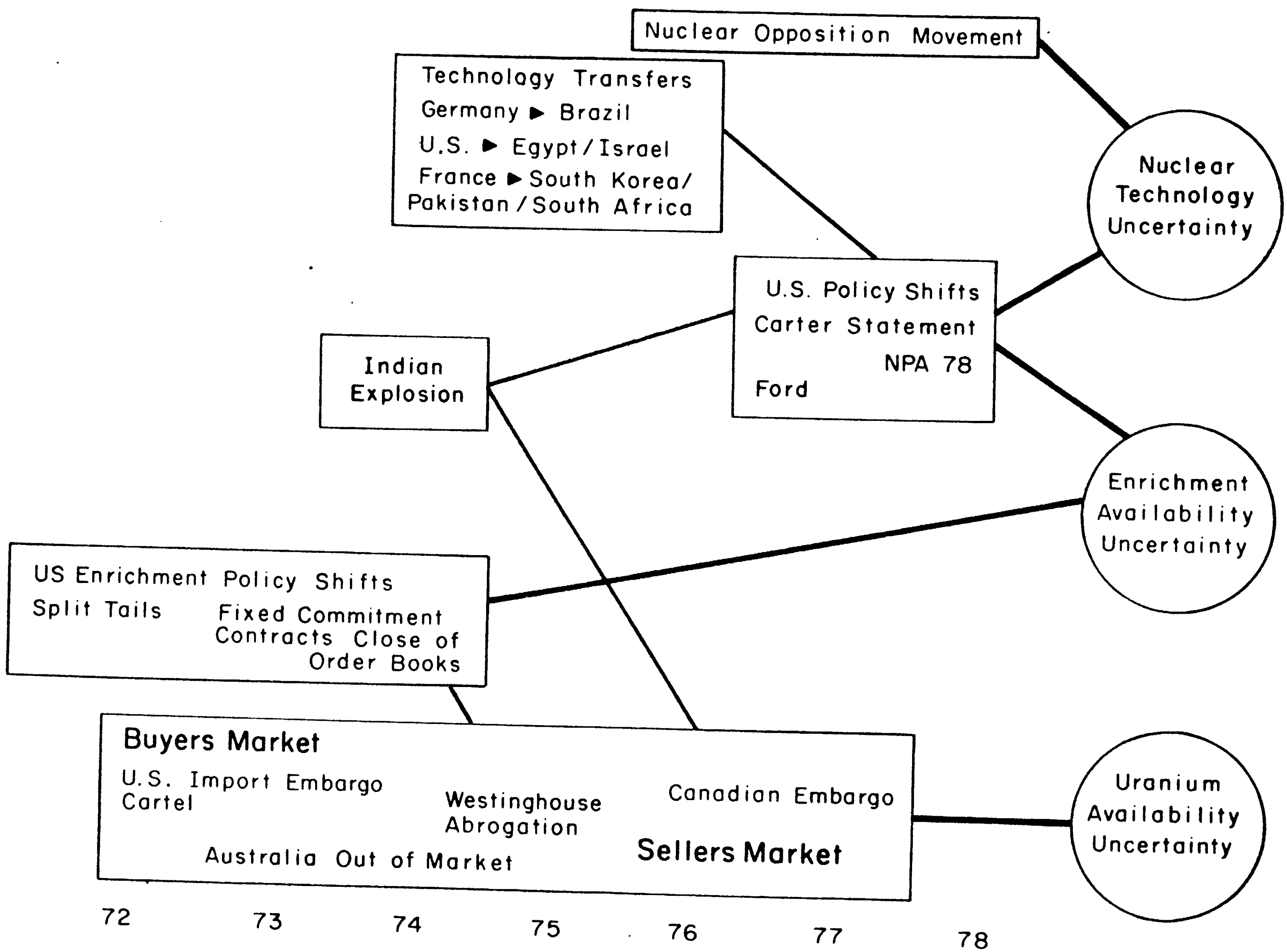

Figure 4. Events affecting nuclear fuel assurance and their interrelationships.

particularly large impact. By the end of 1972, the U.S. had entered into Requirements Contracts for 107,000 MWe of nuclear capacity, 25,000 MWe of which was for foreign customers. In January 1973, the AEC announced its intention to offer only Long-Term Fixed-Commitment Contracts. Moreover, the AEC announced that contracts would be issued only for reactors requiring enrichment of initial cores before July 1982.

By July 1974, ERDA (which incorporated the AEC enrichment functions) had executed Fixed Commitment Contracts for 166,000 MWe of reactor capacity, 42,000 MWe of which were with foreign buyers. Unfilled requests totaled 91,000 MWe (75,000 MWe foreign). Additional firm contracts were written, but 44,000 MWe of reactor capacity (mostly foreign customers) remained unsatisfied. Contracts were offered for this capacity, conditional on the U.S. proceeding with plutonium recycle, and 27 of these conditional contracts were written. To deal with the uncertainties imposed on these customers, President Nixon announced a month later that the U.S. would "in any event" fulfill the conditional contracts.[4]

The effects of the Long-term Fixed Commitment Contracts and the closing of the U.S. order books were significant. Not only did the contracts seem to encourage commitments to large numbers of reactors worldwide (an effect consistent with the large number of reactor orders in 1973 and 1974) but the substantial new long-term commitments put considerable pressure on an already tight uranium market. These effects, combined with a decline in growth of electricity demand, environmental opposition and other factors, led to intense pressure in 1975 for readjustment of the contract arrangements. ERDA responded in mid-1975, with a one-time "open season" -- a period in which delivery, and thus reactor schedules, could be slipped. However, first cores were not allowed to slip beyond 1985, and part of the natural uranium feed had to be delivered on the

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[4]Of the 27, 18 holders of conditional contracts later terminated, some because they had been assigned a firm contract by an earlier purchaser. In 1977, 7 of the remaining contract holders terminated and 2 (both in South Korea) converted to Fixed Commitment Contracts.

original schedule. As of mid-1976, foreign capacity covered by Long-term Fixed Commitment Contracts stood at 78,800 MWe.

Even more important than the pressure on reactor procurement and fuel cycle activities was the effect on the perceptions of foreign consumers and suppliers. These events damaged the confidence of consumers in the reliability of the U.S. as a long-term supplier, and some foreign reactor suppliers initially saw the U.S. move as an effort to induce commitments for new reactors which would be purchased from U.S. vendors. The U.S. move could also have been seen as a pre-emptive effort to tie up enrichment demand before new ventures abroad were in a position to write contracts.

In fact, the changes in U.S. contracting policies are probably best understood as resulting from the effort to shift enrichment to the private sector, begun in the late 1960s, and the desire to make long-term enrichment planning more secure in anticipation of a wave of new reactor orders expected in the late 1970s and early 1980s. While the reasons for privatization were probably more domestic than international--the original intention had been to make nuclear power a private endeavor and there was pressure to cut the size of the AEC budget--there appears to have been suspicion abroad that the U.S. was beginning to convert its traditional "promotion in the name of international security" into a drive for commercial dominance in an increasingly competitive world market. Whatever the facts, these perceptions could only add to the growing uncertainty about future availability of enrichment supplies.

URANIUM Up to 1973, the worldwide uranium industry remained weak. There had been a surge of reactor orders by U.S. utilities in the early 1970s, but it does not seem to have had much effect on U.S. spot prices (see Table 1), and in any event the rest of the world was excluded from the U.S. market by the continuing embargo on imports of foreign uranium. Utilities and consumer governments generally believed that uranium would be available at low prices; there was little interest in long-term contracts, buyers preferring the spot market where prices were falling (in real terms) in mid-1973.

The U.S. government also provided an additional demoralizing shock: just as reactor orders were picking up in the early 1970s, the AEC proposed to dispose of 50,000 STU_3O_8 from the U.S. stockpile. To reduce the impact on the uranium market, the AEC devised a "split tails" contracting arrangement. Utilities would deliver uranium as if the enrichment plants were to operate at 0.20% tails assay.[5] However, the plants would actually operate at 0.25% tails assay with the resulting requirement for additional uranium to be met from the AEC stockpile. This scheme would avoid a sharp blow to the uranium market, though it did mean that U_3O_8 demand would be about 20% lower than otherwise; it also showed that changes in enrichment contracting could suddenly alter uranium market conditions.

With a depressed uranium market in most uranium-producing countries, the atmosphere was created for government intervention, protectionist measures, and cartel formation. In the Spring of 1971 a series of meeting began which were to culminate in the "Club" or cartel of producers, which was active from 1972 to 1974. The government of Canada was apparently responsible for the first initiative, through discussion with Australian officials about uranium marketing strategy. By early 1972, there were reports of a meeting in Paris of representatives from France, Canada , Australia and South Africa intended to "put some order into the international uranium market...to coordinate uranium production and marketing policies" (8).

Cartel documents released later (U.S. House of Representatives, 9) showed the development of a plan to allocate market shares for two periods,

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[5]In enrichment, the feed (at 0.711 percent U235) is split into a product stream of, say, 3 percent U235 and a waste or "tails" stream of anywhere between 0.2 and 0.3 percent U235. For a given fixed output of LWR fuel, the higher the tails assay the more uranium feed is required.

1972-77 and 1978-80, and to establish minimum prices and bidding priorities for sales. The domestic markets of France, South Africa, Australia and Canada were excluded. Minimum prices were set to rise from around \$5.50 to near \$8.00 in the period 1972 to 1978. The cartel appears to have had little effect: by the end of 1972 the spot price (as computed by Nuexco) was still below \$6.00 per pound. By the end of 1973, it had risen only to \$7. The cartel may thus plausibly be viewed more as a symptom of the depressed market conditions of an earlier era than as a successful effort to control market allocations and price in a period of rising demand for uranium. In this regard, it was very different from the OPEC oil cartel.

Conditions in the uranium market did ultimately tighten, and prices rose, far beyond the expectations of the cartel organizers. However, the causes of these changes must be sought elsewhere. The relevant events are suggested in Figure 4. U.S. enrichment policy had a strong effect, for the introduction of LFTC contracts produced a surge in U_3O_8 demand in late 1973 and early 1974. Changes in uranium supplier government policies had similar, but smaller, effects: in 1972 a newly elected Labor Government put a lid on Australian exports; Canada (in September 1974) adopted a domestic reserve policy which required that a fraction of reserves be set aside for domestic use; and France (in April 1974) withdrew from the supply of uranium due to its new commitment to a much expanded reactor program. Finally, there was the Westinghouse abrogation of uranium supply contracts which was announced in September 1975, but had been rumored since 1974.

Of these events, the largest effects appear to have come from the large commitments to new reactor capacity in connection with the Long-term Fixed Commitment Contracts, and (in the United States) from the Westinghouse abrogations. The effect of the new enrichment contracts was two-fold: utilities were forced to take a longer-term view of procurement, and the new demand represented a sizable increase over previous expectations. The first cores (initial fuel loads) under the new contracts would require procurement by foreign customers of an extra 35,000 STU_3O_8(at 0.20 % enrichment tails assay) before about 1980, compared to deliveries under Requirements Contracts of about 20,000 STU_3O_8; annual requirements for reactor reloads were to be increased comparably after 1980. The increase in domestic U.S. delivery commitments was much smaller.

The net result of all this was a shift upward in demand, occurring at the time when Australia had indicated its unwillingness to enter the market, and Canadian and French supplies were being reduced. At the end of 1973, outstanding U.S. utility invitations for bids stood at 40,000 tons (10). As shown in Table 1, spot prices began to rise in 1973, probably more slowly than they might under these circumstances since Westinghouse's short position was still secret.

Prices continued to rise during 1974, doubling by the end of the year. During 1974, U.S. producers and agents sold 17,600 tons to domestic buyers and 5,200 tons to foreign purchasers, who were appearing in the United States for large quantities for the first time (the previous year saw foreign sales of only 500 tons). Moreover, in 1974 the AEC announced that the U.S. ban on foreign uranium would be lifted beginning in 1979, and by the end of the year U.S. utilities had contracted for 33,000 tons abroad. (Previous U.S. purchases abroad were reported by the AEC as being only 7,000 to 8,000 tons total.) The procurement activities of U.S. utilities abroad increased the pressure on supplies available to foreign utilities.

In the resulting seller's market the first "market price" contracts were written (the Canadian Rio Algom contracts with Duke Power and TVA). Other changes also began to appear. Increasingly, utilities moved to arrange procurement directly: by the end of 1974, 68% of total U.S. forward delivery commitments had been arranged directly by utilities. The remainder were arranged by reactor vendors or other agents. By the end of 1974, rumors about the Westinghouse situation began to surface. So also did suggestions by ERDA that it would have to raise the tails assay on which uranium delivery requirements were based (a result of a revised stockpile policy), thus increasing the amount of uranium that U.S. and foreign utilities would have to deliver to the enrichment plants.

Uranium prices doubled again in 1975 in this volatile atmosphere. ERDA's open season on Long-term Fixed Commitment Contracts gave an opportunity to reduce demand pressure for deliveries in the late 1970s. But Westinghouse made its first disclosure of its short position in July and in September claimed "commercial impracticability"[6] and declined to deliver on contractual responsibilities. The result was another scramble for new contracts and a further bidding up of prices. The main effect appears to have been on the domestic U.S. market: U.S. purchasers contracted for 16,200 tons from domestic suppliers and 4,400 tons from foreign sources; in contrast U.S. producers sold only 900 tons to foreign buyers (13).

In 1976, there were further changes in the uranium market as consumers and producers responded to growing uncertainties with a wave of vertical integration. Instead of contracts for deliveries, producers began to propose joint ventures with long-term financing arranged by utilities. This process had actually started during 1975, but the major impact on procurements waited until 1976 when a record 92,900 tons were contracted between domestic U.S. producers and consumers. Of this quantity, some 47% was from primary sources in which purchasers had a direct involvement (13).

A similar picture was emerging outside the U.S. However, the energy security interests of countries like West Germany and Japan, and the risks of making investments abroad, led to relatively high levels of

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[6]A claim initially based on the OPEC price increases and embargo but later changed to allegation of uranium cartel price manipulation. The Westinghouse contracts affected were virtually all with U.S. utilities; only Swedish utilities were affected abroad. See Joskow (11). Also, an excellent analysis of U.S. enrichment policy in this period has been prepared by Charpie (12).

government involvement, either directly or through financing, guarantees or other subsidies. Government backing for foreign uranium ventures also reduces the risk of supply interruption by host country governments, particularly where the latter is in joint venture with the foreign entity.

The development of these patterns of integration appears to have stabilized the uranium market, though perhaps at the expense of making it less responsive to future changes in supply/demand relationships. Prices have not risen and indeed have fallen in constant dollars since mid-1976. The new procurement level in the U.S. fell back to 12,000 tons in 1977 (2), a figure comparable to annual production levels.

The uranium and enrichment market stabilization which began in 1976 is not the end of the story on fuel assurance concerns, however. Indeed, just as market problems were being resolved, a series of political events further disrupted nuclear fuel supply arrangements.

THE CHANGING POLICY CONTEXT The new difficulties arose out of an increasing politicization of nuclear exports due to proliferation concerns. The precipitating events, indicated in Figure 4, were the Indian explosion in (1974), and trade deals involving the transfer of reprocessing and enrichment technology (in 1975 and 1976). The planned technology transfers were from France and Germany--as new suppliers--to Pakistan, South Africa, South Korea and Brazil. These events reflected a change in the international balance of commercial and political influence in nuclear matters. The entry of new suppliers reduced the leverage of traditional nonproliferation leaders, like the United States, and this happened at a time when technological change and international technology transfers were bringing into question the capabilities of the nonproliferation regime negotiated during the preceding decade. The consequences for fuel assurance were profound, since nuclear fuel supply was the primary remaining form of direct leverage over the nuclear activities of other countries retained by traditional suppliers.

Canadian Policy Changes Canada, whose exports had been used by India to produce a nuclear explosive, responded first with a series of changes in export policies. In December 1974, Canada called for a renegotiation of existing agreements and the retroactive and prospective imposition of new nonproliferation conditions on all uranium contracts with other countries. While Canada was able to modify agreements with some countries (for example, Argentina), progress with Switzerland, Japan and the Euratom countries proved difficult. The renegotiation period ended in December 1975. After two subsequent six-month extensions had expired without agreement, Canada announced a uranium export embargo. At the same time, Canada further increased the stringency of her export criteria. Under the new regulations, new contracts, or contracts pursuant to existing agreements, would be approved only if the consumer country accepted the NPT or agreed to safeguards on its entire peaceful nuclear program, a provision commonly referred to as "full-scope" safeguards. Canada also required a prior approval condition on reprocessing and retransfers to third parties, a pledge not to develop "peaceful" nuclear explosives, and implementation of Euratom-IAEA agreements on the latter's safeguards role.

The Canadian embargo was relaxed by early 1978, with a temporary remission of disagreements aided by events outside Canada. Policies were changing in the U.S., as discussed below, and the International Fuel Cycle Evaluation (INFCE) was begun. INFCE provided an opportunity to deal with the Canada-Euratom dispute by postponing resolution of the renegotiation issue until the year following the completion of INFCE. During the interim period, Canada has suspended its original demands for veto power over reprocessing, enrichment and retransfer; now only "prior consultation" is required. The interim agreement, developed in December 1977, was made without prejudice as to the outcome of ultimate negotiations: to grant Canada a suspension of its veto would have implied Euratom recognition of the Canadian veto power. The interim agreement thus represents a suspension of the sensitive prior-approval issue (a position weaker than that in the U.S. legislation discussed below). In exchange, however, Canada did achieve the implementation of trilateral safeguards agreements with the non-weapons states in Euratom and the IAEA and with the IAEA and the U.K. France, the principal stumbling block in the Euratom negotiations, was to have negotiated a separate agreement with the IAEA but has not yet done so; in the interim, there is agreement that Canadian-supplied material will not be transferred within Euratom to France.

In addition, there was the negotiation (in December 1977) of an interim Canadian-U.S. agreement on "double-labeling" (i.e., the imposition of separate safeguards systems by two countries). Under the agreement, the U.S. is committed to consult with Canada concerning imposition of safeguards conditions prior to releasing Canadian-origin material (e.g., following enrichment in the U.S.). This arrangement provided the key to resolution of a disagreement between Canada and Japan. Japan renegotiated its agreement with Canada to reflect the new Canadian conditions in January 1978. The new agreement provides for Canadian approval of safeguards on reprocessing, enrichment, storage and retransfer.

Another factor which may have been important in Canadian accommodation was the economic significance of uranium exports to the nation and to the uranium industry; both remembered the hard economic times which had only recently given way to rising uranium sales at increasingly high prices. As early as March 1977, news reports indicated mounting pressure from the uranium industry for resolution of the safeguards deadlock. The embargo had tied up contracts worth more than $300 million. Late in 1977, the Canadian Trade Minister was quoted as saying that Canada was waking to the "commercial realities" of its safeguards policy (14). Such a mixture of nonproliferation and commercial interests undoubtedly will remain an important factor in the future evolution of Canadian policy.

U.S. Policy Changes While the Indian explosion stimulated an early response in Canada--due to the direct involvement of Canadian equipment--the effect on U.S. policy was slower to develop. The U.S.

first responded to the German and French technology transfers by attempting to intervene directly with the countries involved or indirectly through the London Suppliers group (discussed below); basic shifts in nonproliferation policy came later. In part, this delay was due to the fact that nonproliferation policy was complicated by a growing pluralism and ambiguity in the policy formulation process.

The Energy Research and Development Reorganization Act of 1974 began to open up what had been a monolithic nuclear policy process within the AEC and the Joint Committee on Atomic Energy. Licensing of exports was assigned to an autonomous Nuclear Regulatory Commission (NRC) which began to play a day-to-day, independent role in interpreting nonproliferation conditions. Such a system would have been relatively stable in an era with little change in international nuclear problems and little need for change in U.S. policy. However, with rapidly changing international conditions, the NRC was put in the uncomfortable position of having, in its routine licensing decisions, to play an important foreign policy role. In March 1975, the NRC began a policy of closer scrutiny of potentially sensitive exports by the commissioners themselves; this change in procedures delayed licenses and was widely interpreted abroad (and still is) as an export ban. In West Germany, the Research and Technology Minister stated that the "export ban underlines the need to become as independent as possible from foreign energy sources" (15). That even small changes in procedures could raise such concerns revealed a growing uncertainty about the reliability of U.S. supply, and increasing sensitivity to the security of nuclear fuel generally.

In 1976, the question surfaced in the Congress. Attention focused on the conditions imposed on U.S. exports, and on the roles to be played by a host of federal agencies. The legislation considered in this period included almost all the provisions of the Non-Proliferation Act of 1978.[7] This activity resulted in little actual change in U.S. policy.

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[7]The emerging mood of the Congress is well reflected in an article by Senator Abraham Ribicoff (16). He proposed measures, including reactor market sharing and provision (or withholding) of fuel, to lower the incentives for other suppliers to transfer proliferation-sensitive materials and technology.

However, lack of clarity in U.S. export procedures, growing dissonance in the policy formulation process, and indications of incipient changes in the basic assumptions and modes of action underlying U.S. policy, tended to increase uncertainties about the market and sovereign costs which would be associated with future supplies from the U.S.

These issues came to a head in the later days of the 1976 presidential campaign. The Ford Administration promulgated a new domestic policy on reprocessing and recycle of plutonium: technological extension of the fuel cycle would be considered necessary only when economic or other benefits outweighted proliferation risks. While this was a relatively conservative statement compared to those emerging in Congressional debates and in some parts of the arms control community, it established an unusually strong linkage between domestic nuclear policies and foreign policy objectives.

The Carter Administration carried the debate further in a major announcement of April 7, 1977. Domestic reprocessing and recycle of plutonium were deferred indefinitely and the commercialization phase (though not longer-term R&D) of the breeder reactor program was suspended. Alternative fuel cycles, which inhibited access to weapons material, were to be emphasized in U.S. programs; fuel assurance was to be improved by increasing U.S. enrichment capacity and re-opening the order books; the historic refusal of the U.S. to export enrichment and reprocessing technology would be continued; and the U.S. would explore ways to insure adequate energy supplies multilaterally while reducing the spread of capabilities for nuclear explosive development. It was at this point that the President called for an International Nuclear Fuel Cycle Evaluation (INFCE). In addition, there was a suggestion (in response to a press question) that supply of fuel by the U.S. could be used as an instrument of compulsion as well as assurance.[8] In subsequent actions,

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[8]The statement was unclear: "If we felt that the provision of atomic fuel was being delivered to a nation that did not share with us our commitment to nonproliferation, we would not supply that fuel."(17)

the U.S. initiated the renegotiation of Agreements for Cooperation to reflect new nonproliferation conditions.

During this same period the new Congress was completing a committee reorganization which abolished the Joint Committee on Atomic Energy and established the exclusive oversight of international nuclear policy in the House International Relations and Senate Foreign Relations Committees. This step, and the emergence of an Administration position, led eventually to the passage of the Nonproliferation Act of March 1978 (NPA 78). The terms of this Act are the result of a process of compromise between Congressional attitudes and those of the departments and agencies of the executive branch. The major difficulty was to find a way to establish uniform conditions for nuclear exports, which would make approval predictable (if basic nonproliferation conditions were met) while preserving flexibility for the executive in dealing with specific situations. To provide this, the Act specifies sequential and conditional procedures involving the various governmental actors (the NRC, the President, the Departments of State and Energy, the Arms Controls and Disarmament Agency, and Committees of Congress).

In summary, the Act says the following. In order to qualify for U.S.-supplied fuel, an importer must have an Agreement for Cooperation, negotiated by the Secretary of State with participation by DOE, ACDA, and NRC. The requirements for such an agreement include: 1) safeguards on all exports and material produced with exports, 2) IAEA safeguards on <u>all</u> the peaceful nuclear activities of a non-nuclear-weapons country ("full-scope" safeguards), 3) a pledge not to use any U.S.-provided material or equipment for research into or detonation of an explosive device, or for any other military purpose, 4) the U.S. right to require return of any exported material in the event of an explosion or abrogation of an IAEA safeguards agreement, 5) U.S. prior consent before retransfer, reprocessing, enrichment, or storage of any exported material, 6) adequate physical security measures, and 7) a guarantee that any facility built using technology transferred under the agreement would be subject to similar conditions. Many of these criteria for Agreements can be exempted by the President for foreign policy or security reasons, though the President is directed to renegotiate all existing Agreements for Cooperation to incorporate the new antiproliferation restrictions. Various committees of the Congress then have the opportunity to review the Agreements.

The 1978 Act also adds two other amendments containing criteria which are to be appled by the NRC to each specific export license. They are virtually the same as those to be included in the Agreements for Cooperation, except that only the full-scope safeguards requirement (number 2 above) can be waived by the President, under limited conditions and subject to Congressional disapproval. Thus, while the provisions in the Agreements for Cooperation are subject to negotiation between the U.S. and the recipient party, the criteria governing license approvals are almost all imposed by the U.S. legislation. The process of obtaining an exemption on the full-scopes condition, starting with a Presidential decision, is a laborious one, involving several congressional committees and consulations with the Departments of State and Energy, ACDA, and the NRC.

Not suprisingly, then, a basic objection to the Act, raised by a number of countries, is that it does not provide a clear and predictable export policy. Many of the situations to which it applies will not satisfy the general conditions, and recourse to the exemption procedures will be required. This procedure introduces less predictable factors (e.g., Presidential override of the NRC sustained by Congress for every export license). It is thus difficult for some countries to regard the Act as providing much greater assurance of supply, especially those that have not accepted full-scope safeguards or have nuclear technology commitments which would be threatened by the prior approval conditions. Ironically, some of these are countries in which assurance may be most important as a nonproliferation measure. Perhaps attempting to compensate for lack of manifest improvements in assurance through export policies, the Act creates a separate institutional mechanism to deal with fuel assurance concerns, an International Nuclear Fuel Authority. The extent to which such a mechanism can deal with fuel assurance concerns--especially those of countries whose primary uncertainty is U.S. export policy--is an issue of considerable importance.

Other Suppliers Australia is in the process of defining its export criteria after a reappraisal of its role in the uranium market and in the nonproliferation regime. An Australian-Finnish agreement in 1978 may prove to be a model for subsequent bilateral arrangements with other customers. Under the accord, Australia reserves the right to prior consent before re-export of uranium to third countries. The agreement contains a pledge not to divert any Australian material to military purposes. IAEA safeguards are to be applied, and Australian consent is required before re-enrichment or reprocessing of supplied uranium can take place. Australia reserves the right to suspend shipments in the event of a failure to observe the terms of the contract or adhere to IAEA safeguards. Australia's requirements are thus generally in line with current U.S. export conditions.

Similarly, the position of the USSR is close to that of the U.S. The USSR will provide toll enrichment services only to those countries who have agreed to full-scope IAEA safeguards. Also, the USSR also puts conditions on retransfers of Soviet-enriched uranium to third parties. The Soviet record is one of a strong supporter of the NPT regime.

Several developing countries, such as Niger, Gabon, and Brazil are or may be sources of uranium. Indications are that the export policies of most of these countries will be governed by commercial needs; nonproliferation and other political conditions generally do not appear to apply.

The export policies of key European suppliers, most importantly of France, are not yet clear. An important forum for discussion of export policy issues has been the London Suppliers "Club", an initially secret group of representatives of nuclear exporting countries. During the past three years the group has agreed to increasingly restrictive common export conditions. However, there is not complete accord on the much more stringent conditions recently adopted by the U.S. and Canada. Thus though recent changes in U.S. and Canadian policy can be seen as desirable efforts to strengthen the international nonproliferation regime, there remains considerable tension between the U.S. and other supplier and consumer countries, who may perceive a different balance of commercial interests, energy insecurities and nonproliferation concerns. Since the principal source of direct leverage of the U.S. and its nonproliferation allies--on consumers and other suppliers alike--is through the control of fuel, the security of fuel supply has become closely linked to differences over nonproliferation conditions as they relate to nuclear development internationally.

The resolution of these differences--or the failure to resolve them--will be a major factor in the future evolution of the nuclear fuel supply system and will affect the reality and perceptions of nuclear fuel assurance. At present, many of these disputes are in suspension or under negotiation. The International Nuclear Fuel Cycle Evaluation has provided a breathing space for national re-evaluation of nuclear power issues and objectives in an international context. It has also allowed a temporary remission in particular disagreements, such as that between Canada and the Euratom countries. However, probably the most important fact about INFCE is that it will end, in late 1979 or early 1980. The reconstruction of a common political and commercial context for nuclear power development, and thus nuclear fuel supply, must be well under way by this date if fuel assurance is not to suffer new setbacks.

IV. TRENDS IN DEMAND, CAPACITY AND STOCKS

For most of its history, the nuclear fuel market has operated in an environment where political constraints on exports were uniform over most of the world, and where export license procedures were predictable. It is only in the last two or three years that political conditions on fuel trade have appeared to be such a serious threat to nuclear fuel security. Both in INFCE and elsewhere, efforts are under way to construct a new international understanding, and complementary national policies, which will provide a smoothly-functioning, dependable system of fuel trade while meeting nonproliferation goals.

There is hope that such an accommodation can be reached, and if this proves so then the outlook for nuclear fuel assurance is favorable. With nuclear capacity growth lower than expected, the pressure on fuel supply systems has been reduced. Tight market conditions and the fuel assurance concerns of the past have stimulated investments in uranium mines and mills and in additional enrichment capacity. Conservative planning by utilities and governments has resulted in a build-up of fuel stocks which provide a cushion against future problems. We are also beginning to see increasing diversity in nuclear fuel supply industries and the creation of markets with greater stability and flexibility in responding to changing conditions. With some help from the intrinsic resilience provided by long fuel cycle lead-times, it has been possible to avoid interruption of nuclear electricity generation despite extreme shifts in supply conditions.

Of course, optimism must be tempered by recognition of the problems that remain. There is a potential for disruption due to cartelization of uranium supply, or the failure of some key producer. Also, there is concern about the ability of producers to expand capacity in the medium term. And ultimately, as we shall see, there is uncertainty about resolution of the political differences which affect the terms of international trade in nuclear fuel. In search for the discernable trends, and remaining problems, we look first at enrichment, and then turn to uranium and stockpiles of low-enriched fuel.

ENRICHMENT

During the next several years, the availability of enrichment will increase, both in total capacity and in diversity of sources. Additions currently committed are shown by the solid lines in Figure 5, along with the most recent OECD estimates of demand.[10] Ventures planned but not committed could add to this capacity in the latter years of the period, as the dashed lines indicate. Fear of inadequate enrichment capacity may have been an assurance problem in the past; but as Figure 5 makes clear, the next decade will be a period of considerable excess capacity. What is more, this surplus exists for subsets of nations as well as for the world as a whole. If each country is credited with its equity share in any venture in which it participates, plus its contracts with other suppliers, then one finds that only the URENCO group (largely West German utilities) faces tight supplies through the 1980s. Japan, the Eurodif partners and a group of "all others" are each going to be in a circumstance where supplies substantially exceed reactor requirements.[11]

Of course, in interpreting these figures a number of qualifying factors must be kept in mind. The demand calculations are based on the OECD/IAEA nuclear growth estimates, assuming 0.20% tails assay and a 70% capacity factor for reactors. These assumptions tend to overstate requirements: some enrichment will be done at higher tails assays (at a 0.25% assay, about 13% less enrichment is needed than at a 0.20% assay), and reactor capacity factors have been consistently below 70%. Moreover, the reactor growth projections are based on firm plans only out to the mid 1980s; beyond that time they are based on expectations that historically have

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[10]The capacity of enrichment facilities is stated in Separative Work Units (SWU). About 111,000 SWU are required to enrich the fuel to operate a 1000 MWe LWR for one year at 70% capacity factor(assuming a 0.25% tails assay for enrichment plant operations). The Soviet capacity shown is not the total USSR enrichment capacity but only that capacity which has been contractually committed to exports outside the Soviet Block. The quantities indicated are thus a lower bound on those potentially available.

[11]These analyses are presented in greater detail in Neff and Jacoby (18).

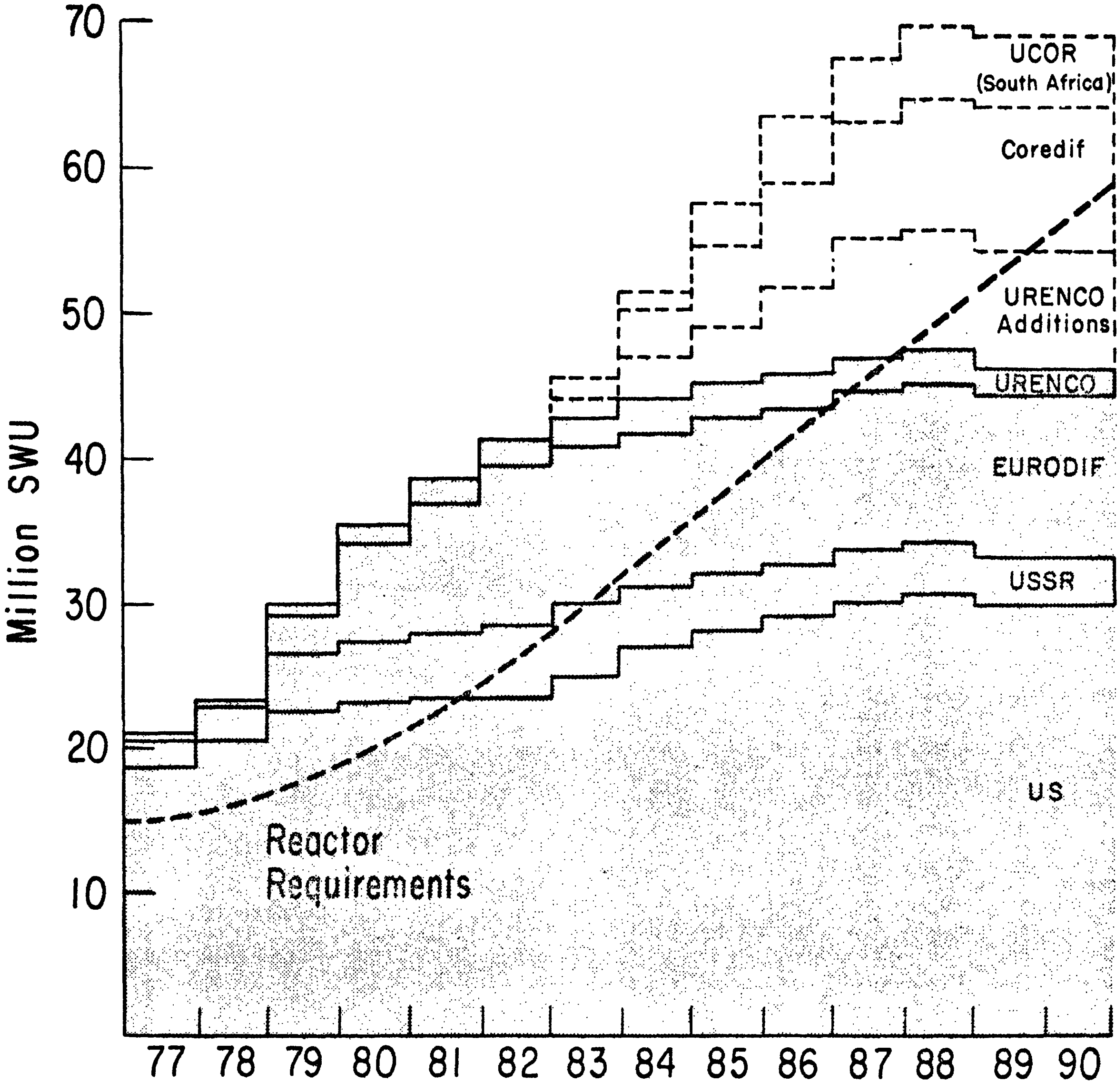

Figure 5. Enrichment capacity expansion as compared with projected reactor requirements. Reactor requirements are based on the December 1977 OECD/IAEA nuclear growth projections [1], assuming 70% reactor capacity factor and 0.20% enrichment tails assay. The solid lines indicate committed enrichment capacity and the dashed lines planned capacity. The capacity shown as available from the USSR is only that committed under current contracts; presumably it could be increased.

overstated actual growth. Thus the estimates shown are probably best thought of as upper bounds on demand.

The supply projections are uncertain as well. Capacity actually utilized could be less than shown. The U.S. has already delayed planned investments to increase the capacity of existing diffusion facilities, and has postponed commitments and reduced the size of new enrichment facilities using centrifuge technology. Changes as of the end of 1978 are already included in Figure 5, but U.S. plans could slip further if demand forecasts continue to be reduced, or if there is a shift to other suppliers. In the latter years of the period, capacity could be greater than that shown, but it seems unlikely that reactor growth will pick up enough to justify substantial additions to capacity.

The data in Figure 5, and the recent changes in U.S. enrichment plans, reflect a fundamental change in the enrichment market. With such excess capacity and the entry of new suppliers, there is a possibility of substantial shifts in the worldwide pattern of enrichment trade. These shifts could be motivated by consumer desires to lower risks by diversificaton of supply or to avoid supply situations in which political risks are high. Of course, previous contracts, equity holdings and regulatory constraints tend to reduce this flexibility.

URANIUM

The international uranium market, which went through such extreme changes in the mid-1970s, now appears stronger and less susceptible to large fluctuations. Annual transaction volumes have decreased to levels more comfortably in line with annual production. Producers again have material available for spot market sales and capacity for future delivery. Prices are declining in constant dollar terms (see Table 1) and there are reports that the "market price" contracts of recent years are becoming less common. These changes reflect a swing away from the extreme seller's market of the 1974-77 period. While the market could repeat its historical pattern of extreme changes in transaction volumes and prices, it is likely that the fluctuations will be smaller than in the past simply because the base of firm civilian demand is larger. Moreover, in the domestic U.S. market at least, better mechanisms are evolving for dealing with fluctuations, such as mediation clauses for price disputes and agents and brokers who can arrange loans or sales of material or act as leasing intermediaries. Internationally, such market instruments are less developed, though there is evidence that enrichment suppliers (like Eurodif) can play a mediating role.

In assessing trends over the next decade or so, a number of factors are relevant. Uranium demand will be influenced by reactor growth and operating performance, contract terms for enrichment, and the stockpile aspirations of utilities and consumer governments. On the supply side, prospects depend not only on the amount of material that is there to be found (which of course is uncertain) but on the level and quality of exploratory efforts in different countries and on the many factors which determine the supply from known resources (environmental restraints, political conditions, availability of finance, and so forth.). Moreover, both the supply and demand for uranium can be influenced by changes in technology. Many of these factors are interactive: for example, reduced expectations about demand may cause supplier governments to restrict domestic expansion of uranium industries and regulate exports. Given this complexity and the large uncertainties involved, it is not surprising that there is a wide variation in perceptions of future market conditions.

URANIUM DEMAND The demand for uranium is most heavily influenced by reactor capacity growth. Reactor growth in turn is itself only weakly dependent on uranium prices (which may account for 10% or less of delivered nuclear electricity costs). Decisions to build reactors are influenced more by the desires of electric utilities to maintain a mix of generation sources, public acceptance and regulatory conditions, and capital availability (especially in LDCs). Nuclear expansion also is affected by the problems associated with planning lead times which are long relative to those of conventional fossil fueled generation technologies.

Changes in nuclear technology could affect uranium demand in several ways. Improvements in uranium utilization in light-water reactors could reduce demand by 15% or more, compared to projections based on present technology and practices; much of this gain might be had well before the end of the century. Similarly, advances in enrichment technology, such as laser isotope separation, would allow an increase of about 30 percent in the fuel manufactured from a given input of U_3O_8. Ultimately, new types of reactors--such as very efficient thermal converters or breeder reactors--could lead to dramatic reductions in uranium demand (a factor of perhaps three for converters and fifty for breeders). However, major changes in reactor technology cannot appreciably affect demand for uranium until some time late in this century or early in the next.

As seen above, enrichment contracting requirements and governmental actions play a significant role in the near term. Until recently, government planners, here and abroad, have analyzed uranium demand in the early to mid 1980s on the basis of enrichment contracts rather than actual reactor requirements. In the mid 1970s this was a perfectly reasonable assumption, for uranium needs were in fact determined by the terms of LTFC contracts with the U.S., the dominant enrichment supplier. In addition, these forecasts of uranium needs were predicated on DOE plans to raise tails assays in the 1980s in order to meet what appeared then to be large contract requirements with the available U.S. enrichment capacity. In the past year this picture has changed. Reactor demand has slipped far below that anticipated, resulting in a reduction in the overall expectation of uranium demand, and the resulting excess enrichment capacity has removed the need to increase tails assays. As a result, requirements for natural uranium will be significantly less than originally anticipated and those utilities and countries that contracted for uranium on the basis of the earlier assumptions will find themselves with growing stocks. Moreover, the introduction of Adjustable

Fixed-Commitment Contracts in the U.S., and real competition from abroad, has increased the flexibility of fuel planning.

Stock-building is another important influence on demand. As noted earlier, uranium stockpiles (natural or enriched) have been built for several reasons. They have appeared accidentally, as a result of mismatch between reactor needs and enrichment or uranium contracts; they also have been built up intentionally as a cushion against short-term market disruption or as part of a longer-term fuel assurance strategy. In some cases the quantities are large. For example, Japanese utilities have contracted for over 150,000 tons of U_3O_8, with more than 85% of this to be delivered before 1990; this contracted supply may exceed actual reactor needs duing this period by as much as a factor of two.

Observation of past contracting behavior suggests that as long as significant fuel supply uncertainties remain, consumer planning will be biased in favor of uranium contracts exceeding actual reactor demand. This conservatism may weaken somewhat if stocks accumulate and the trend toward increased supply stability continues.

URANIUM SUPPLY   The future supply of uranium will be a function of the resource and reserve base, the conditions under which the supply industry operates, and the nature of the market system in which uranium is traded. The first of these factors is important only in the longer term, since reserves already proven appear adequate to fuel any reactors built over the next two decades. However, industrial development and market performance are issues of pressing concern in the near and medium term.

Uranium development problems are similar to those in other mineral industries: there is an increasing desire of regional or national governments to control or obtain compensation for the environmental and social impacts of extraction activities, and to realize the best return for the resources. And as is obvious from earlier discussion, difficulties are amplified by the strategic role of nuclear fuel in energy supply and weapons proliferation and the regulatory scrutiny generally applied to things nuclear.

Uranium industries in various producer countries are at very different stages of development; they operate in different geological environments and deal with different sets of political, institutional and environmental problems. In the United States, a large number of independent companies are involved in production from relatively small deposits in sandstone formations in which new inexpensive high-grade deposits are increasingly unlikely to be found. The activity is moving--in the classic pattern of mineral industries--toward lower-grade or deeper and more costly deposits. The major issues are rising labor and other costs, increasingly stringent environmental requirements, and state efforts to capture rents through extraction taxes. The relatively weak coupling between the U.S. and international uranium markets has restricted the importance of foreign policy issues, which tend to enter more at the enrichment stage.

In Canada, large high-grade deposits are to be mined by relatively few companies, one of the largest of which has significant government involvement. Despite a history of uranium exploration and exploitation, new discoveries of large, high-grade deposits continue to be made. The major influences on development include increasing provincial involvement (economically and environmentally) and--since most uranium is exported--the need to insure stable conditions (and revenues) for the domestic industry while pursuing nonproliferation objectives.

Australia is in a position similar to that of Canada, except that its industrial development is less advanced and there are greater internal political differences centering on nonproliferation, environmental effects and aboriginal-rights. Again, new discoveries of very large, moderate-grade deposits are occurring, and may be expected in the future. The large potential for expansion of Australian and Canadian uranium output raises the question of price maintenance. We will return to this issue, and the possibility of a price-setting cartel.

South Africa continues its export of uranium produced as a by-product of gold, and has plans to recover uranium from old gold slimes and even to produce gold as a by-product of uranium. Thus South Africa is in a position to expand output somewhat and is doing so. The largest prospect for Southern Africa, however, is Namibia, where the Rossing mine is producing at about 3,500 tons per year. Major expansion is feasible and other significant deposits appear to exist, although political change may threaten this output or alter the terms of its availability. Central African production--from Niger and increasingly from Gabon--is becoming more significant in the world supply picture.

Table 2 shows two recent projections of uranium production capacity, one by the OECD/IAEA (1) and one by McLeod and Steyn of NUS Corporation (3). These data show an improving situation from the standpoint of diversity of supply. The U.S., Canada and South Africa continue as major sources, and Australia appears ready to assume a significant market position. Moreover, the "other" category includes a growing number of countries who may be small producers but nonetheless offer the possibility for consumer risk-spreading by diversification of supply sources.

On the question of price, the situation is less clear. With the U.S. as a net importer, Canada, Australia, South Africa and Niger will dominate supply to international trade. As noted earlier, these four nations hold over 80% of known reserves, and any of several subsets of this group (e.g., Canada and Australia) could attempt to establish another international cartel. The longevity of such arrangements is always a question,[12] but there seems little doubt that the machinery is in place to manage the price. Both Canada and Australia have government boards with control over export conditions, including price, and both countries have similar political and economic interests.

Of course, such a cartel would very likely encounter the same problems that have plagued other arrangements of this kind. The nations

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[12] Eckbo (19) reviews the history of some thirty international commodity cartels and for the successful ones the usual life has not exceeded four to six years. Oil appears to be an exception, but whether uranium will fall in this category is not known.

Table 2

Projections of Uranium Production Capacity[a]

(Thousands of STU_3O_8)

	1977		1980		1985		1990	
	OECD	NUS	OECD	NUS	OECD	NUS	OECD	NUS
U.S.	19.1	16.0	29.4	23.0	46.8	27.0	61.1	35.0
Canada	7.9	7.2	10.3	9.4	16.3	12.0	14.7	11.0
Australia	0.5	0.7	0.7	1.2	15.3	13.0	26.0	24.0
South Africa	8.7	6.5	15.2	10.4	16.3	13.0	15.6	11.0
Other	6.6	5.7	13.3	11.5	25.0	12.0	25.7	11.0
TOTAL	42.9	36.1	68.9	55.5	119.7	77.0	143.1	92.0

a. The OECD projection is from Reference (1); the NUS projection is from Reference (4) maintaining the price must be able to control net exports from their own suppliers. If domestic capacity (say, in Canada) expands beyond that which the market can take at the cartel-set price, then government authorities must find a way to allocate production among domestic producers. With many domestic operations, each with several international partners, this could prove a very difficult task.

SUPPLY-DEMAND BALANCE Another issue that arises in discussions of fuel assurance is the capability of the industry to expand in the medium term. The mineral resources may be there, and the market conditions favorable, but it may be difficult to marshal the capital, labor or environmental clearances necessary to expand capacity. Or at least there may be long delays.

Different assumptions about these problems are implicit in the estimates in Table 2. In Figure 6, these capacity figures are compared with uranium requirements derived from OECD/IAEA reactor growth estimates. As discussed above, these growth estimates are probably high. The tails assay for enrichment is set at 0.20%, and no consideration is taken of intentional stock building.

Both supply projections show an excess of production capacity over reactor needs in the near term. In the longer term, the OECD uranium capacity forecast remains above projected reactor needs while the NUS projection drops below projected demand in about 1987. It is in the early 1980s that the OECD/IAEA and NUS estimates begin to diverge significantly. Both projections are based on industry expansion plans and normal development of reserves and resources. However, the OECD/IAEA projection is a "could do" estimate which assumes success in dealing with the problems of industry expansion. A number of difficulties of doing so are discussed but not explicitly reflected in the estimates. The NUS projection, on the other hand, assumes continuing difficulty in fulfilling plans; a delay of three months per year in all industry plans is assumed as well as a 3 percent loss from each year to the next due to declining grade.

The combination of the NUS forecast, or others like it, and an independent projection of reactor demand may suggest to some that capital expansion in the uranium industry will not keep pace with the expansion of nuclear electrical capacity. But this is not necessarily the case. When such independent projections are made for any resource, there almost

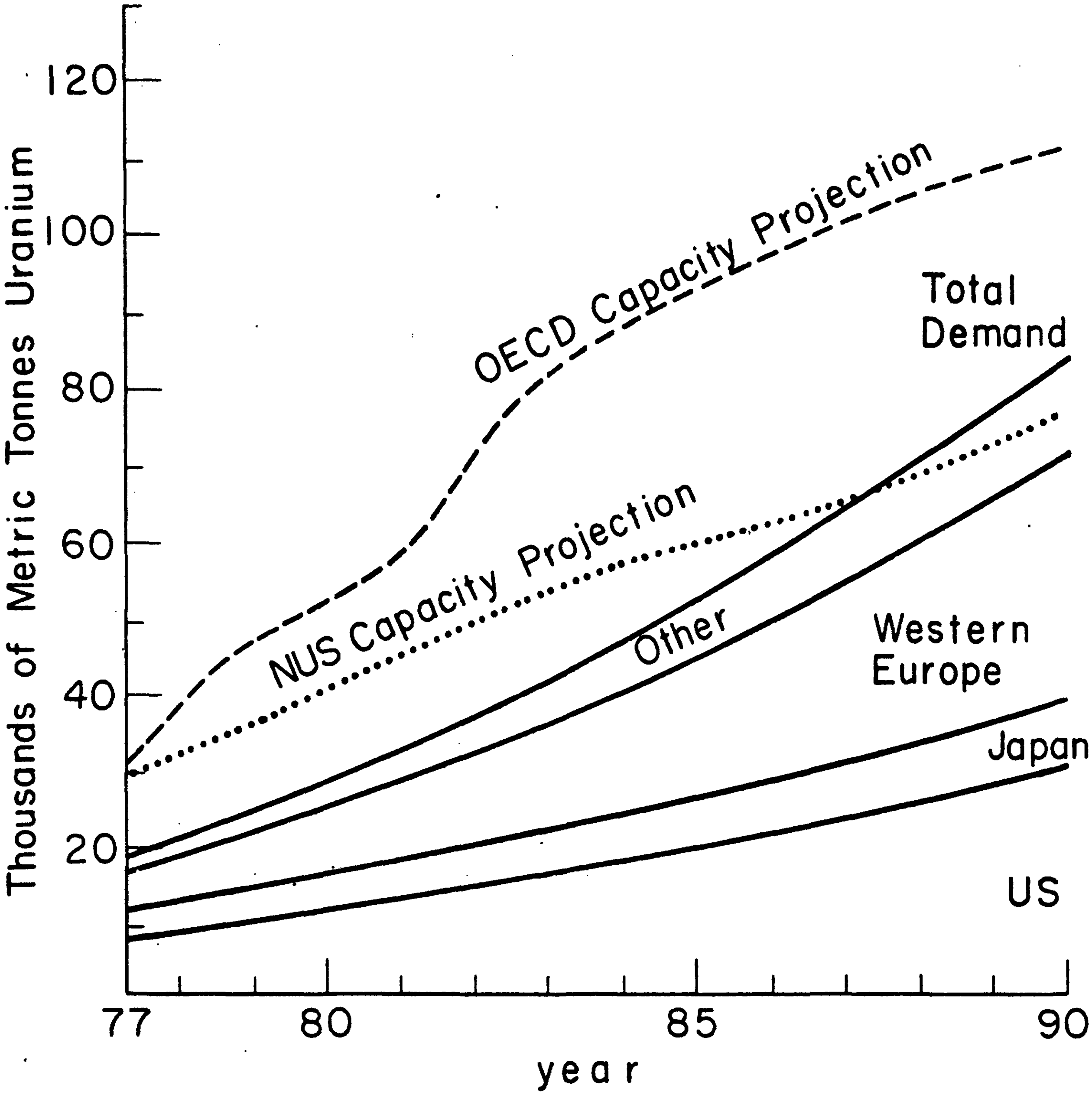

Figure 6. Comparison of potential uranium demand with uranium production capacity projections. Demand is based on the OECD/IAEA projection [1]. The two uranium production capacity projections are from references [1] and [3].

always is an apparent mismatch between capacity and demand, especially as projections are extended beyond the time horizon of the firm industry commitments. The resulting "gaps" are often misinterpreted as portending important economic and security problems.

However, the independent projection of capacity and demand neglects the fact that these quantities are kept in balance over time by a dynamic process of equilibration in which producers and consumers adjust their plans, expectations, and activities. The "gaps" which appear in independent forecasts of capacity and demand simply indicate the magnitudes of the adjustments which must, and generally will, be made to the plans or assumptions on which the projections are based; they are not unavoidable catastrophes. The crucial issue is the process by which this adjustment takes place. Many depletable natural resources are traded in well-organized commodity markets, with only a minimal level of direct political intervention. In these cases the process is simple, if sometimes painful. Rising demand leads to increased prices, which provide incentives for increased production and dampen demand growth. The risks of dealing with fluctuations and uncertainties in the process are shared by suppliers and consumers by means of long-term contracts and, occasionally, multinational marketing agreements.

The process of equilibration in uranium is more complicated than for many other natural resources, due to the special characteristics of the fuel cycle, demand inelasticity, and heavy government involvement. Nonetheless, there is strong evidence that uranium will prove very similar to other resource industries in its responsiveness to price and expected future market conditions. For example, there has been a strong increase in exploratory activity, and in mine and mill investment over the past three years. Indeed the major factor in discussions of continued commitments to this industry is the likelihood that the price will continue to soften, as it has in recent months (see Table 1).

Moreover, the fuel cycle itself provides some room for adaptation to imbalances in uranium supply and demand over periods for a few years--even without modification of reactor plans. If there is great excess capacity in uranium, some stabilizing influence can be introduced by raising enrichment tails assays, a change that may happen naturally if prices fall far enough. Similarly, if the uranium market tightens, tails assays can be lowered (though at 0.20% they now appear to be near the economic optimum for diffusion plants).

Finally, it is important to note that the time now required to license and build a new nuclear reactor is about the same or longer than that needed to bring new uranium production capacity on line. While government planners and utilities undoubtedly would feel more secure if supply commitments preceeded demand, it is thus far more natural that reactor commitments should lead uranium industry investments.

Of course, it is always possible that the mechanisms which lead to a balance between supply and demand could be dealt a blow so severe that the responsiveness of uranium supply would be severely damaged. There could be some unforeseen environmental problem that would affect a number of consumers; depletion rates world-wide could turn out to be much higher than now expected; or a very large producer (such as Australia) could suddenly cease exports. None of these developments seems likely. Indeed most trends seem to be in a favorable direction on these counts, assuming for the present that it is possible to achieve a more uniform set of nonproliferation conditions on nuclear fuel trade. Nevertheless, these developments are not certain, and industry expansion could be retarded by short-term market uncertainty, perhaps magnified by the policy actions of key exporter governments. Therefore this set of issues is an important focus for further analysis.

STOCKPILES OF LOW-ENRICHED FUEL

The projections in Figures 5 and 6 indicate that it would be possible to build up large stockpiles of uranium, or low-enriched uranium, over the next decade. Of course, potential is not realization, and the cost of building and holding these stocks is great even given that the enrichment capacity is available. This aspect of the system may be illustrated by a calculation of the possible stockbuilding given firmly planned enrichment capacity and possible uranium production capacity.

Such a computation is shown in Figure 7. The size of the stockpile is stated in terms of the number of GWe-years of reactor reloads that the projected capacity could provide in excess of the OECD/IAEA demand forecasts; and the capacity factor and tails assay assumptions are those used earlier. These stocks if built would correspond to roughly 1400 GWe-years of fuel by the late 1980s, given the full-scale operation of enrichment facilities already committed. This quantity would represent about three years forward supply for the entire 470 GWe estimated to be on line in 1990.

The largest stocks would develop in the systems served by the U.S. and Eurodif plants. The smallest would be in the utilities of Germany, Great Britain and Holland, the partners in Urenco. While there appears to be adequate supply for the latter, there is not a very large margin. Of course, additional enrichment may be contracted for elsewhere. Urenco centrifuge capacity can be expanded well before 1990, and reactor demand in the Urenco partner countries very likely may slip. The relatively large stocks among U.S. utilities and at DOE are due largely to demand slippage and to continuation of a historically large unassigned stockpile; the large stock among Eurodif utilities is due to slippage in the reactor growth originally assumed when the Eurodif countries (especially Italy) made their commitments to the facility.

This is the quantity that could be built up should utilities and governments be willing to pay for them. Current evidence is that they are not: DOE is cutting back drastically on power inputs to its enrichment plants (estimates are of 12.5 million SWU in FY 1978 and 14 million in 1979, whereas capacity is over 17 million SWU). So the stocks will surely be less than shown in Figure 7.

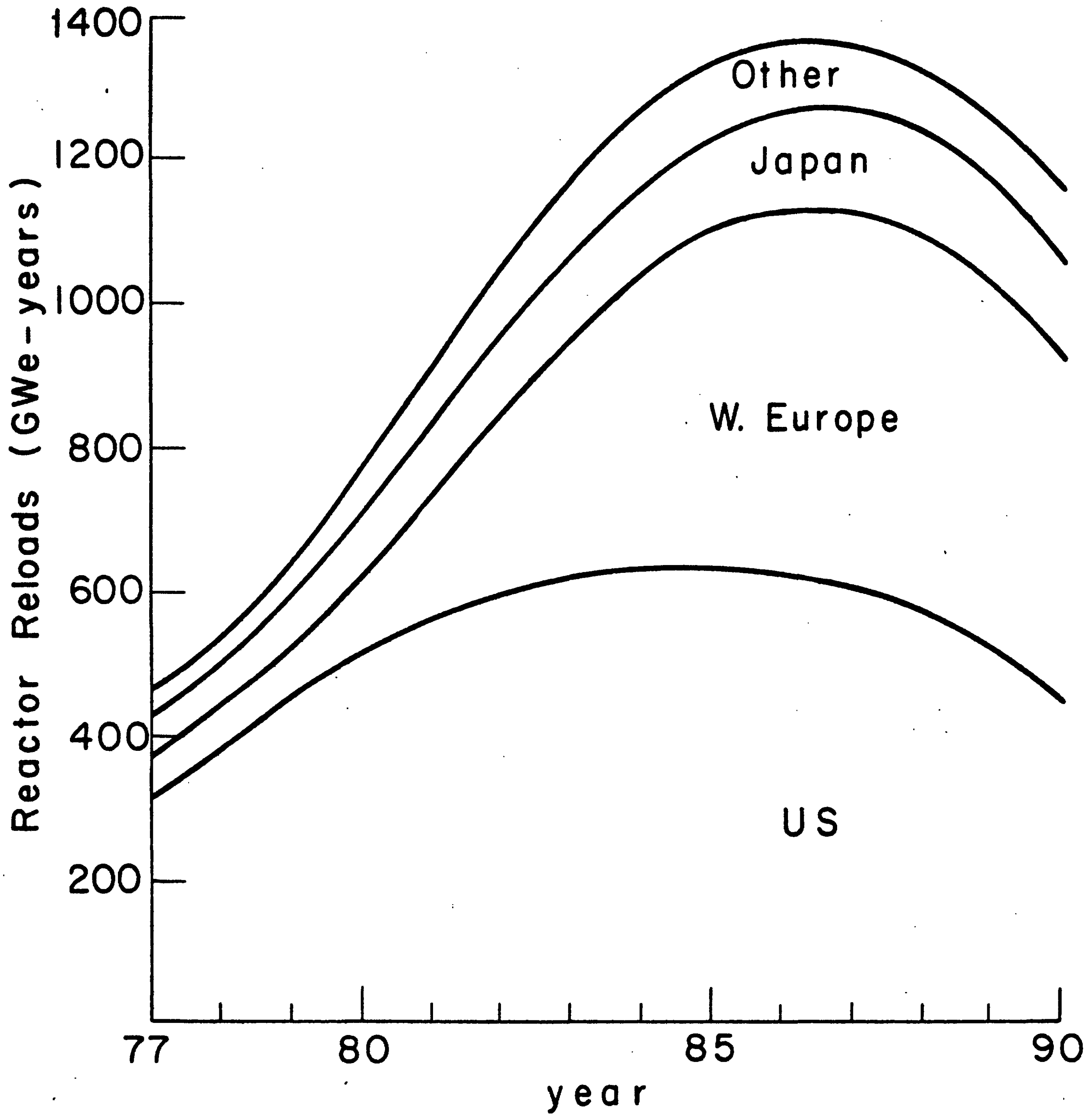

Figure 7. Potential cumulative stockpiles of low-enriched uranium fuel (expressed in terms of power generation capability). These projections assume that enrichment capacity or contracts in excess of actual needs are used to produce fuel for stockpiles. Only committed enrichment capacity is assumed; if planned capacity were built and used, stocks would continue to grow in the late 1980s. Adequate uranium would be available to build such stocks only if production comes close to the OECD projection in Figure 6.

Nevertheless, even with substantial cutbacks in enrichment plant operation, the stocks held worldwide are quite large now and will grow over time (though not necessarily in proportion to total reactor throughput). This level of stocks, and forecast stock holding, bodes well for fuel assurance. The system as a whole is well situated to deal with short-term disruption, and over the next few years there will be substantial capability to increase output in the event of short-term supply-demand imbalance.

In short, the system is now demand limited and will be for the next five years or more. Thus "fuel assurance" for consumers is high relative to the last few years, provided all buyers have comparable access under the nonproliferation regime. Problems of uranium capacity expansion may loom in the late 1980s, but that problem is deeply interdependent with current uncertainty about the future of reactor growth itself. That is, to the extent that there is a medium-term uranium production capacity problem, it is more a symptom than a cause of problems in the nuclear industry, and an analysis of trends indicates that the uranium market can adjust to meed demand (perhaps at rising prices) given some reasonably stable expectations about what demand will be.

V. CONCLUSION

In past years, nuclear fuel assurance problems have resulted from a number of factors, including the unique technical structure of the industry, the high degree of supplier concentration, unhealthy market conditions and market failures, and the changing policies of countries selling uranium and enrichment services. However, as one looks ahead to the next decade or two, the risks associated purely with monopoly or oligopoly of supply no longer appear to dominate the fuel assurance problem. The actions which now feed concerns about assurance are often those which are taken in the name of nonproliferation. Here there is a disturbing paradox, for the desire to remove fuel insecurity as an incentive to the spread of sensitive facilities and materials comes into conflict with new supplier policies which put increasingly restrictive conditions on fuel availability.

At present the international nuclear fuel system seems to be at a point of unstable equilibrium. For the duration of INFCE there is a set of arrangements which allow trade in uranium and enrichment to continue, even though long-term agreements remain to be renegotiated. At the end of INFCE, this balance will very likely be perturbed, and the world trading system will move toward one of several conditions. On the one hand, there may evolve a coherent, consistent set of nonproliferation conditions applied to all fuel customers worldwide. This might occur through a decision to decouple nonproliferation policy from export conditions on LWR fuel, or by common agreement on the means by which fuel supply will be used as a policy instrument. A uniform market for fuel would result, with the issues of full-scope safeguards and vetos over reprocessing and retransfer somehow resolved.

Another possibility is that agreement on nonproliferation conditions will not be reached, and some suppliers will continue with a set of rules less restrictive than those insisted upon by the United States, and perhaps Canada and Australia. In this case, the nuclear fuel market may split; consumer countries would be put in the position of choosing between further constraints on sovereignty (in the form of full-scope safeguards or restrictions and uncertainties about their technology development) and reductions in the diversity of supply. The ultimate effect of such a development on proliferation risks is beyond our scope.

But the likely effect on fuel assurance is clearer. To the extent that segmentation takes place, the security of nuclear fuel supply would probably be reduced for nations in the smaller market with fewer nonproliferation restrictions. Thus, one of the most important determinants of fuel assurance in the next few years is the resolution of current disputes over nonproliferation conditions. A satisfactory accommodation of varying supplier interests and policies is of crucial importance to the health of future nuclear markets and the security of nuclear fuel supply.

In the U.S., the ability to deal with this situation beyond the next year or two will be complicated by underlying assumptions in current nuclear policy, especially as it is formulated in the Non-Proliferation Act of 1978. As discussed above, the Act has at its core the assumption that U.S. provision of fuel and other nuclear assistance gives the U.S. leverage over developments abroad. In effect, the Act extends the carrot of fuel security to developing countries and others, under the condition that they accept U.S. restrictions on nuclear power decisions. The stick of a possible withholding of fuel supply is applied not only to these countries but to the major industrialized supplier states as well. The prior approval condition on retransfers and reprocessing is one way to ensure consideration of U.S. nonproliferation concerns in the majority of sensitive international transactions, as well as in foreign domestic nuclear programs. However, this control is not universal and given the excess capacity in enrichment (shown in Figure 5) and the availability of uranium from suppliers not imposing stringent nonproliferation conditions, it may soon be possible for an important corner of the world fuel market to emerge from the shadow of a nonproliferation policy based on fuel cycle control.

At present, the Administration is taking advantage of the exemption provisions in the Act, and the 18- to 24-month implementation period for the full-scope safeguards requirement, to soften its impact, while drawing recipient countries closer to the U.S. position. Indeed, the existence of the more restrictive legislation may temporarily enhance the Administration's negotiating position. However, while the Act may thus contribute to U.S. nonproliferation goals in the near term, its ability to improve long-term fuel assurance is questionable. For the large number of countries apparently unwilling to accept extensive exercise of U.S. power over their nuclear programs, dependence on the exemption procedures cannot provide the predictability which is the basis for low-enriched uranium fuel assurance in the longer term.

It is thus clear that fuel assurance is deeply intertwined with a set of larger nuclear policy issues: not only are the conditions of access to fuel supply dependent on resolution of larger political differences between nations, but fuel is being used as a source of leverage in the resolution of these differences. From the standpoint of fuel assurance, a key issue for the future is the manner in which the U.S. policy, expressed in the Non-Proliferation Act of 1978, will be adjusted to a world in which the basic assumption underlying the Act--the continued existence of U.S. fuel cycle control--is gradually losing its validity.

While it is our general conclusion that there is considerable reason for optimism about the functioning of the supply system, given resolution of current political conflict over export conditions, there are other factors which will influence the performance of fuel markets and thus affect fuel assurance. One area of policy concern is that of fuel stockpiles. Today's stockpiles have accumulated because of government purchase programs, preproduction and other aspects of enrichment plant operations, and delays in reactor start-up. Once created, such stocks can change the future environment in which the uranium industry operates, in constructive or destructive ways depending on how the stocks are managed. For example, great fluidity in stocks could reduce incentives for producers to maintain inventories for spot market sales. Recent changes in enrichment plant operations (the end of the split tails policy) and budgetary pressures appear to have stabilized the magnitude of U.S.-held stocks, though there is still some question as to how these stocks will be utilized.

Stockpiles also affect fuel assurance. If widely held, stocks can increase the shock-absorbing capability of the nuclear fuel supply system, making it possible to deal with short-term interruptions or delivery problems. At present, utilities with established nuclear programs appear to hold one, two or more years forward supply. In addition, the governments of major consumer countries (like the FRG, France, the U.S. and the U.K.) hold additional stocks. A more subtle assurance issue is whether countries with small but expanding nuclear programs have adequate access to such buffering stocks. In principle, these stocks could be made available to countries with insecure but smaller requirements on a loan, sale or lease basis. However, the fundamental issue from the perspective of the recipient is likely to be the terms of access. This will be an especially difficult consideration for small consumer countries who believe their primary fuel assurance problems are the proliferation-related access conditions imposed by major suppliers.

Fuel banks have been proposed as a solution to the short-term assurance problems of small consumers lacking buffer stocks. A relatively small bank (equivalent, say, to 10 GWe-years of reloads) might help alleviate assurance fears in these countries; it might also function as a symbol of concern on the part of the suppliers. However, the value of a small fuel bank is at least in part conditional on resolution of the larger political conflict over terms of trade discussed above. Without such resolution it seems unlikely that the Congress and the Administration could relinquish control over a bank contribution.

There has also been a proposal for an International Nuclear Fuel Authority (a major component of NPA 78). Such a system would replace a significant fraction of the present market, with its overlay of bilateral and multilateral conditions, with a global authority allocating fuel under uniform conditions. The establishment of a Fuel Authority appears to require the achievement of the international agreement and political accommodation discussed above, as well as success in developing a major new international institution able to respond to and balance the needs of many nations. We believe that this is probably impossible. Moreover, if it were possible to achieve the first condition, there would be little need for such an institution. Indeed, many countries (Japan, West Germany, etc.) have a stronger international trade orientation than the U.S. and would prefer to trust their ability to satisfy their needs in international markets, especially if the larger political uncertainties can be removed. The Fuel Authority proposal would undoubtedly raise fears of costly economic inefficiencies and a potential for politicization of allocation. It is also not evident that such a system would provide a superior environment for expansion of the uranium industry or satisfy the diverse interests of key supplier countries.

A second area of concern is the evolution of uranium markets. We have argued that general conditions in the uranium market have improved, shifting back somewhat from the extreme seller's market of the mid 1970s. However, there are impending changes. The renegotiation of enrichment contracts by the U.S. over the next year will free a portion of the uranium market which had been the captive of stringent enrichment plant delivery conditions. This potential demand reduction comes at a time when Australia is re-entering the market and large new uranium discoveries are being made. The result may be a softening of the uranium market. While this may be advantageous in the near term to consumers seeking supply assurance, there may again be a reduction in uranium investment incentives, leading to concerns about longer-term supply adequacy.

Changes in the character of the uranium market may also increase the likelihood of government intervention. In Canada and Australia, there are already mechanisms in place for managing export quantities and prices. In addtion, these governments could use existing environmental and other barriers to control the pace of internal industry development. Instituted in a seller's market era, such governmental control may be perceived as even more important in an era of weakening prices. The dangers in cartelization would be the possibility that capacity creation could fall out of step with demand growth, and that the supplier countries could use their supply leverage to extract new sovereign as well as market costs. The policies of Canada and Australia are thus of great significance to the future security of uranium supply.

Beyond the cartelization issue, there is concern about continued reliance on suppliers whose output may be disrupted, perhaps for reasons having little to do with nuclear power. For example, disputes in Southern Africa--within South Africa or over the independence of Namibia--could lead to disruption of supply. The stability of Australian supply may depend on the resolution of nonproliferation issues, and on the success of the nonproliferation regime in inhibiting nuclear weapons acquisitions and use. New proliferation events could result in political changes, in Australia or other supplier countries, making continued supply uncertain. Efforts to establish or maintain stable export policies in key supplier countries and to resolve nonproliferation problems are thus important to fuel assurance in the current highly concentrated uranium market.

Finally, there are measures which might be taken to improve medium- and long-term assurance. These include better assessments of worldwide uranium resources and a program of investments in better data commensurate with the societal value (which exceeds the commercial value) of such information. Also needed is better information on world trade patterns in uranium and nuclear fuel so that vulnerabilities and impending problems may be identified in time to take (or avoid) action. In addition, limited measures might be taken to improve market mechanisms. These could include removal of barriers, or the creation of incentives, for the entry of new uranium suppliers. What is needed, in our view, is not additional institutional overlay, but rather efforts to avoid future problems in the evolution of healthy trade relationships, within the framework of the nonproliferation agreements which dominate the assurance issue.

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